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Investigation on SOE performance under elevated pressure with AC:DC operation

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Abstract

By 2030, solid oxide electrolyzers (SOEs) are expected to be a key electrolysis technology, due to their high electrical efficiency, low material costs, and dual functionality as fuel cells. The main challenges for SOEs are limited stack lifetime (e.g., 20,000 hours) and cell size (e.g., 100 cm2). A new operational method for SOE, named 'AC:DC', patented by DynElectro in 2019, has shown promise in addressing the key challenges. This method involves overlaying an alternating current (AC) on a direct current (DC), allowing intermittent operation in fuel cell mode. Tests on SOEs indicated that AC:DC can enhance lifespan by removing temperature variations and improving impurity resilience through electrochemical oxidation/reduction processes.

Capital expenses (CAPEX) for balance-of-plant equipment such as heat exchangers, pipes and compressors can be reduced by 50% when increasing the operation pressure from ambient pressure to 5 bar for SOE. Additionally, high pressure operation enables increased hydrogen production capacity for SOE.

In present study, the MESH project aims at building a setup and conducting SOE cell testing under elevated pressure (up to 5 bar) with AC:DC operation. The preliminary experimental investigations are presented. Furthermore, the dynamic SOE operations during the testing are discussed from system point of view.

Introduction

Electrolysis technology emerges as an efficient solution for storing or utilizing renewable electricity as green hydrogen and contributing to grid balancing. The produced hydrogen could be further utilized as a sustainable fuel to decarbonize industries and transportation as well as synthesizing green fuels and chemicals to drive the green transition. By 2050, global electrolyzer capacity is poised for a dramatic expansion, reaching Terawatt-scale [1], and contributing to over 15% of global energy consumption. The reliability of electrolyzer systems is crucial for their effective, economical, and safe deployment accross sectors (e.g., energy, industry, chemicals, and transportation). However, there remains a significant and urgent gap in the research dedicated to this critical aspect, for instance, the reliability of an electrolyzer system under different operating conditions (e.g., dynamic operations) remain poorly understood.

Solid oxide electrolyzer (SOE) system which is anticipated to be one of the main electrolysis technologies over the coming decades [2]. In terms of reliability, the primary issues are the performance degradation and scale-up of SOE cells (or stacks) [3], which becomes more pronounced under actual operational conditions, such as load fluctuations following renewable energy variations, compared to laboratory settings.

A new operation method for SOE named “AC:DC” has been proved to effectively address the challenges mentioned above [4][5]. Different from the conventional electrolysis process by providing direct current (or voltage) for water splitting, AC:DC operates with a pulsed operation where an alternating current (or voltage) is applied on top of a direct current (or voltage). In other words, rapid reverse pulses are added to the direct current (or voltage), under the short reverse pulses the electrolysis reaction (consuming electricity and producing hydrogen/heat) goes to the opposite direction and works in fuel cell mode (consuming hydrogen/heat and generating electricity) (as shown in Figure 1).

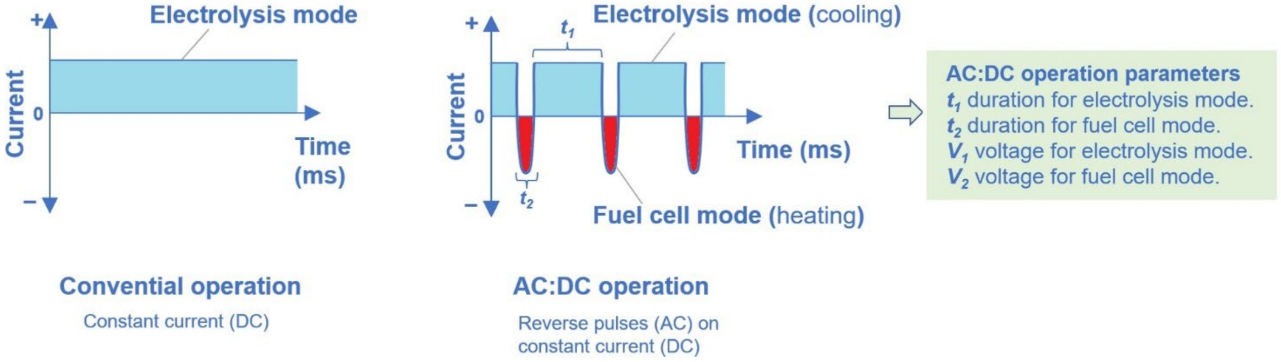


Figure 1. Scheme of AC:DC operation for SOE [4].

The AC:DC operation is able to lower the temperature variation (mentioned in challenge B) across the SOE cell by balancing the heat consumption/generation with the electrolysis mode (endothermic) and fuel cell mode (exothermic) as shown in Figure 1. Additionally, AC:DC has been proved to improve impurity tolerance of silica-containing impurity (mentioned in challenge A) and improve the durability for SOE electrolyzer. This is due to that under the rapid fuel cell mode the water (steam) generated is expected to shift the adsorption/desorption to the desorption direction [4][6].

The MESH project aims to further investigate the performance of AC:DC operation under elevated pressure (up to 5 bar), which is supposed to reduce capital expense of SOE systems. The study presents the research activities including the set-up design and preliminary testing for achieving the project aim.

2. Set-up design for AC:DC SOE testing

The set-up has been designed to conduct SOE testing at elevated pressure (shown in Figure 2), where a SOE test rig from Fiaxell SOFC Technologies has been added inside a pressure vessel. The test rig is capable of both cell and short stack testing. Equilibar back pressure regulators have been connected to the fuel and air side for pressure control. Additionally, power supply (Kepco BOP 1kW) and system control has been connected to the set-up (shown in Figure 2b). Gamry Reference 3000 has been used for Electrochemical Impedance Spectroscopy (EIS) analysis (not shown in Figure 2).

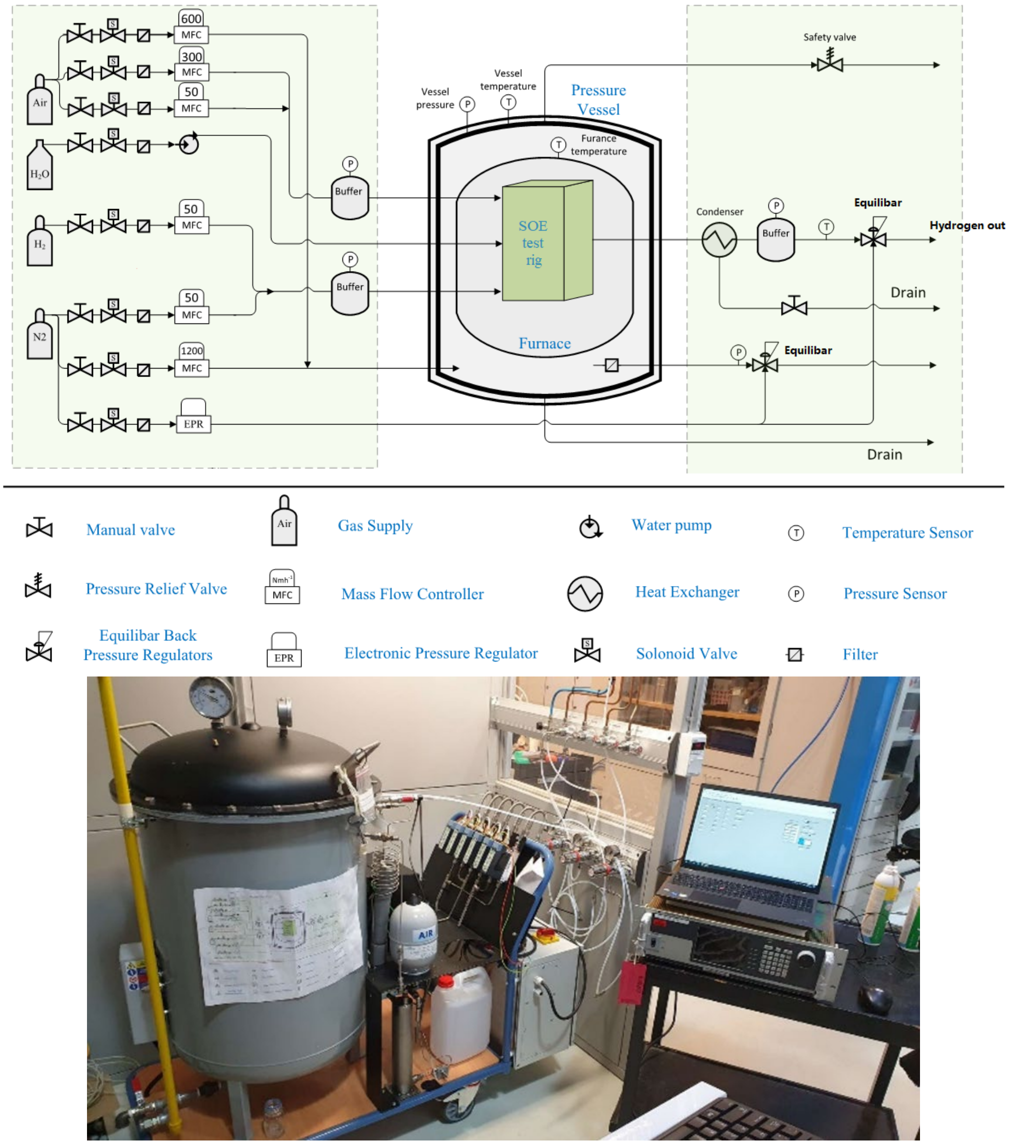


Figure 2. Diagram of system design and set-up picture.

3. Preliminary experimental activities

System testing and adjustment are necessary before pressure increasing. The preliminary experimental activities include cell testing with Fiaxell 2R cell [7], which is “fuel-supported” and has a dimension of 70mm × 60mm. The cell assembly is shown in Figure 3, however, different assembly strategies have been tried due to the cell contact issues occurred during the preliminary testing.

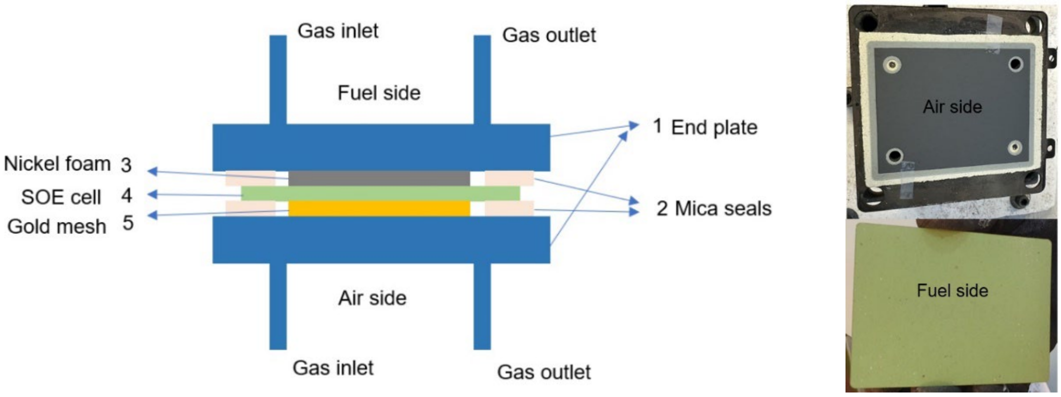
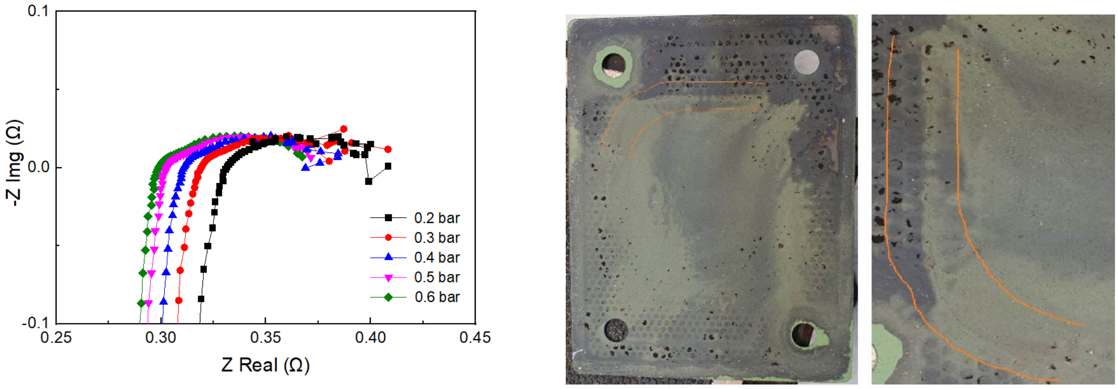


Figure 3. Scheme of cell assembly and SOE cell

The preliminary test with conventional direct current has been conducted with pressure increase only for the fuel side. For this test, the nickel foam layer is not used, cell directly contact the end plate. The following operating conditions have been set: the cell temperature is 700℃, the fuel side gases are nitrogen (45 NL/h), steam (14.9 NL/h) and hydrogen (0.5 NL/h), the air side has flow rate of 10 NL/h. The back pressure for the fuel side has been changed from 0.2 bar to 0.6 bar. The EIS data (Figure 4(a)) shows a decrease trend of ohmic resistance with elevated pressure for the fuel side, and there are noise signals near the low frequency area. However, it is not the conclusion that pressure has a positive influence on cell performance, because obvious cell crack and shape change has been found after disassembly, which results in less active area for the cell and possible leakage between the fuel and air sides.



(a) (b)

Figure 4. (a) Electrochemical impedance spectra for SOE testing at different fuel-side pressure (b) cell picture after the test.

Besides the conventional test, the test with AC:DC operation has been conducted with the following operating conditions: the cell temperature is 700℃, the fuel side gases are nitrogen (10 NL/h), steam (3.7 NL/h) and hydrogen (1.6 NL/h), the air side has flow rate of 35 NL/h, and the currents of 0.15 A and −0.15 A have been set for the electrolyzer mode (30 ms) and fuel cell mode (3 ms), respectively. Also, the nickel foam layer has been used in this test aiming at improvement of cell contact. The cell voltage is shown in Figure 5 with ranges of 1.36 V—1.47 V for the electrolyzer mode and 0.46 — 0.55 V for the fuel cell mode. The results presented a very large cell resistance caused by the contact issue between the nickel foam and the cell, additionally, the fluctuations of cell voltage may be caused by the pressure fluctuations at the outlet of the fuel side, where the form of liquid water may block the outlet tube.

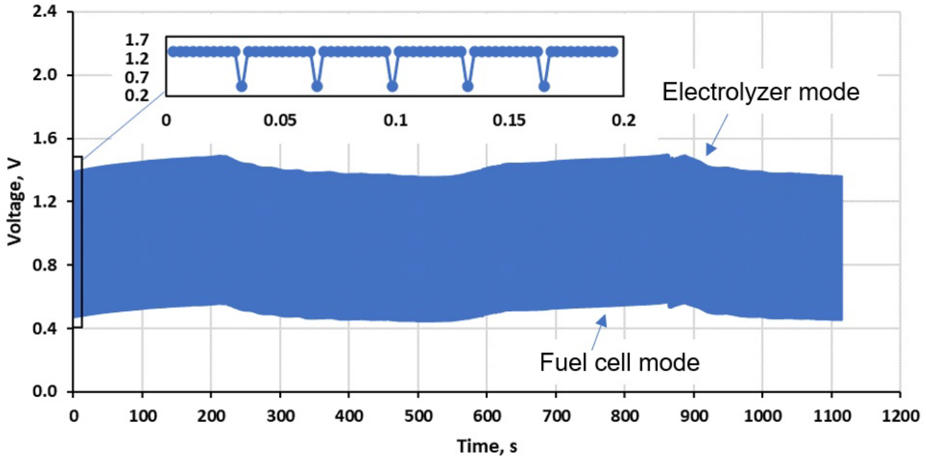


Figure 5. Cell voltage under AC:DC operation.

4. Summary

The MESH project activities on the investigations of AC:DC operation for SOE cell under elevated pressure has been introduced, which includes set-up design and preliminary cell testing. The pressure imbalance (up to 0.6 bar) between the fuel and air sides has resulted in obvious cell damage and possible safety issue, which indicates that carefully pressure control would be required during pressure increase for the system. Additionally, pressure fluctuations in the system could also cause changes of cell performance. Future improvements of cell contact issue and pressure fluctuations of fuel-side outlet are also required before conducting AC:DC operations for SOE cell under elevated pressure.

Acknowledgements

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