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Clara
Venture Labs

High pressure water electrolyser development for exploration surface missions

Executive summary

ESA Contract No. 4000128887/19/NL/HK

Client:

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1: Introduction

The project High pressure water electrolyser development for exploration surface missions (HP-SOC) started in January 2020. During the three years of the project, the consortium consisting of Clara Venture Labs AB (originally named Prototech AS) and Centre of Research and Technology Hellas (CERTH) performed numerous of small and larger task to prepare the use of the Solid Oxide Electrolyser for fuel and oxygen production based on in-situ resource utilisation (ISRU), mainly on the moon. The project has included an analysis of potential missions, establishing most suitable system architecture, mathematical modelling and development and testing of a bread board for high pressure electrolysis. A specific highlight was the successful testing of the SOC stack with the nickel free $La_{0.75}Sr_{0.25}Cr_{0.9}Fe_{0.1}O_3$ fuel electrode which enable direct steam electrolysis to hydrogen and oxygen without the need of hydrogen recirculation. These electrodes are also expected to be especially suited for the dirty lunar water resources containing significant amounts of sulphur, methane, and ammonia. The electrolysis was tested up to 9 bar pressure with gas storage included. This executive summary report summarizes the highlights of the project.

2: Mission requirements and system architecture

2.1 Mission requirements for a generic mission

TN1 establish a first elaboration of mission requirements for a SOEC system used for Lunar ISRU processes. These were the most important qualitative requirements:

- During its lifetime, the total mass of the fuel produced must be orders of magnitude higher than the mass of the system. This emphasizes a robust system with extended lifetime.
- The baseline water resource is icy regolith found in the polar regions. The system should aim towards a direct integration with the water source with high tolerance for impurities.
- The system must be designed to be maintenance free during its estimated lifetime.

- The process will be active during the Lunar daytime of 354 hrs. The temperature will be reduced to a minimum temperature during the lunar night to minimize energy consumption during lunar nights. Required time and energy for start-up must be minimized.

- The focus should be more on reliability and efficient resource utilization than high power density. Thus, redox stable electrodes and operation with high steam utilization, which makes recirculation pumps to be omitted, are emphasized.
- The system must survive thermal cycling, without consumption of fuel.

2.2 Electrolyser subsystem architecture

Three potential system architectures were presented and evaluated in TN2. Architecture #1 was just water inlet, and H_2 and O_2 outlet without any recirculation included. The major weakness was that unconverted water was just disposed, which cannot be accepted.

A more viable architecture is obtained by pumping the water separated from the H_2 outlet back to the water inlet (Figure 1). This simple modification gives 100% water utilisation in the system. There is an additional cost related to producing and condensing steam which is not converted, however, this is acceptable. The inlet feed contains no hydrogen, thus there is a risk of oxidation of the fuel electrode (cathode) if it consists of nickel. This is one reason to investigating the nickel free material $La_{0.75}Sr_{0.25}Cr_{0.9}Fe_{0.1}O_3$ (LSCrFe).

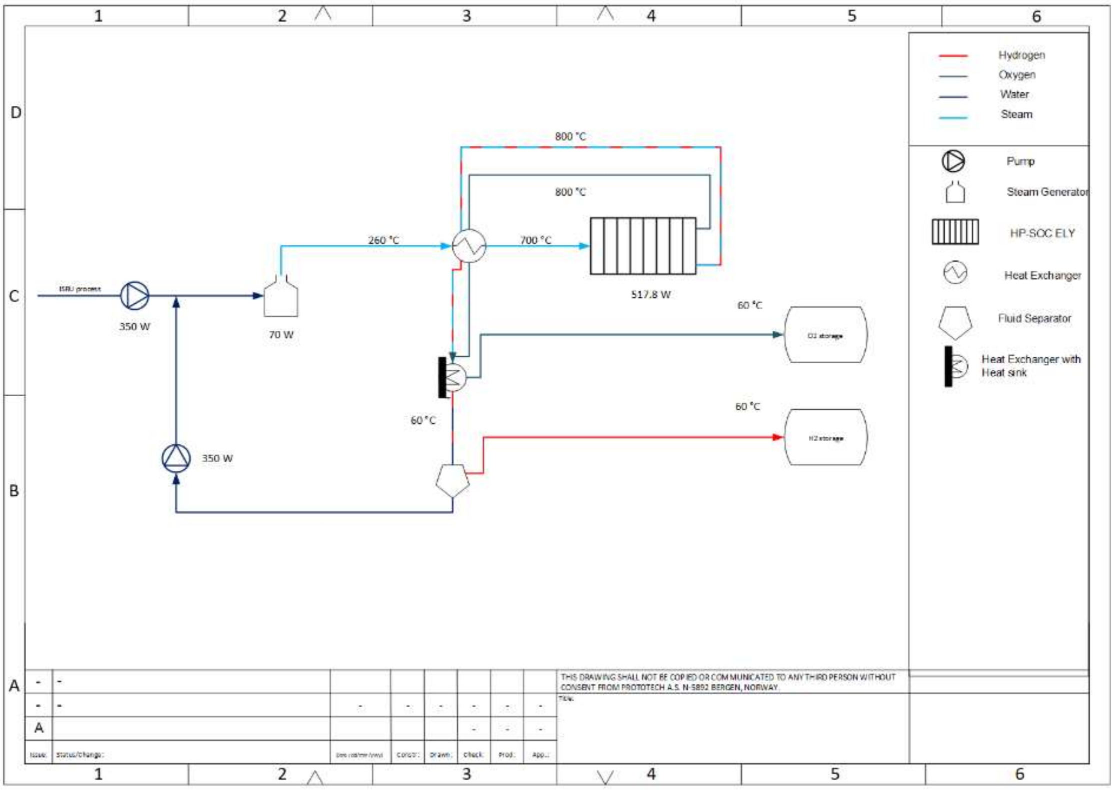

Figure 1. System architecture #2, recirculation of liquid water.

3: SOEC testing

3.1 Single cell testing

Button cells were developed and evaluated under solid oxide electrolysis at high pressure, in order to identify the proper materials configuration for the large cells, to be used for the fabrication of SOEC stacks. In this regard, all three components composing an electrochemical cell were investigated, namely electrolyte, fuel electrode and oxygen electrode. The range of materials considered for testing and the rationalization for their choice were described in TN2 [1].

Figure 2 shows in comparison the performance (I-V curves) at 900°C of the cells with the various electrolytes in reversible operation mode, while 45.5% H_2O in H_2 was fed to the fuel electrode and 100% O_2 to the oxygen electrode. It is evident that the cell with 10Sc1CeSZ electrolyte has the highest performance in both electrolysis and fuel cell mode. The cells with 8YSZ and 6Sc1CeSZ electrolyte present almost the same performance, while the 3YSZ cell follows. Considering optimizations regarding cell preparation and robustness, the 6Sc1CeSZ based cells present the most promising candidate for stack development.

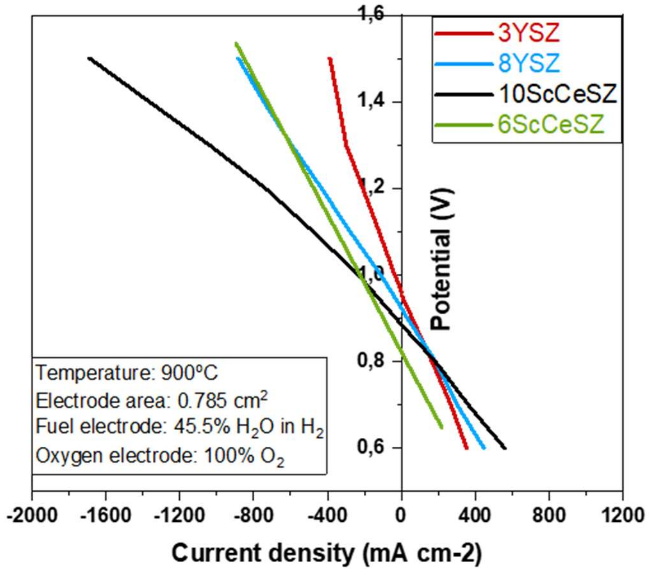

Figure 2. I-V curves for the button cells Pt-LSCrF-GDC//electrolyte//oxygen electrode at 900ºC under reversible operation mode. Fuel side: 45.5% H_2O in H_2, Cathode side: 100% O_2.

Figure 3 presents the characteristic IV curves for a button cell under steam electrolysis at 820°C with a feed of 86% H_2O in He balance at the cathode, for pressure ranging up to 6 bar. As illustrated in Figure 3**,** an increase of pressure up to 6 bar doesn’t seem to have a significant effect on the cell’s performance.

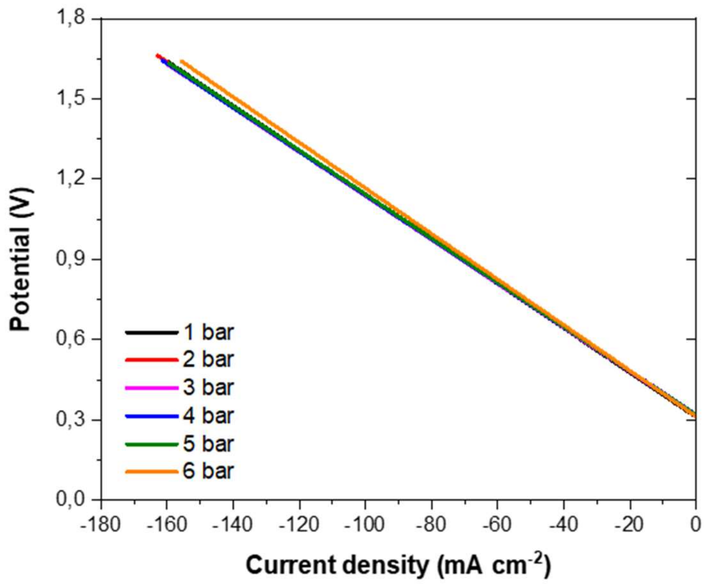

Figure 3. Characteristic IV curves for a button cell under 86% H_2O in He steam electrolysis at 820°C for pressure up to 6 bar.

3.2 Breadboard testing

The bread board testing included several 5-cell short stacks, with standard Ni/GDC fuel electrodes and cells with LSCrF electrodes manufactured by CERTH, a picture of a 5-cell SOEC stack as well as the pressurised SOFC test rig are presented in Figure 4.

Figure 4. Left: Stack mounted on test rig. Right: Test rig for pressurised testing.

Figure 5 show test data for the stack with LSCrFe electrodes during steady state operation at 10 A. The total current can be used to calculate the expected production of 174 Nml/min O_2 and 348 Nml/min of H_2, which has excellent agreement with the measured values. The gas composition measurements show high purity of the produced oxygen with only 3% N_2 coming from the surrounding nitrogen compartment. Also on the hydrogen side, the MS shows mainly hydrogen, it is also known that hydrogen is difficult to quantify with MS, thus we expect the concentration of hydrogen to be higher than what we measured.

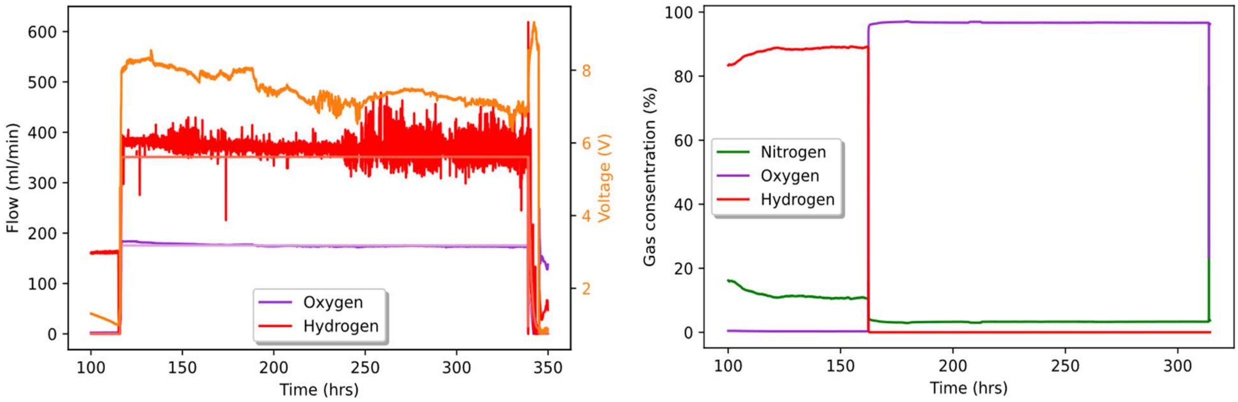

Figure 5. Steady state test data of the LSCrFe cell. Left: Stack voltage, with produced hydrogen and oxygen amount at constant current (10 A). The overlapping lines represent measured values and expected values calculated from the current. Right: Gas composition (dry) measured by mass spectrometry. first sampled at fuel side, then at the oxygen side.

Figure 6 shows test data for the stack with Ni/GDC fuel electrodes during steady state operation at 21 A. Also here, the total current is used to calculate the expected production of 366 Nml/min O_2 and 732 Nml/min of H_2. Also here, there is excellent agreement between the calculated and measured flows, the measured hydrogen flow also includes 60 Nml/min of sweep gas to keep the cathode reduced, which explains the difference shown in the figure. Also here, the gas composition measurements show high purity of the produced oxygen with 1.5% N_2 coming from the surrounding nitrogen compartment.

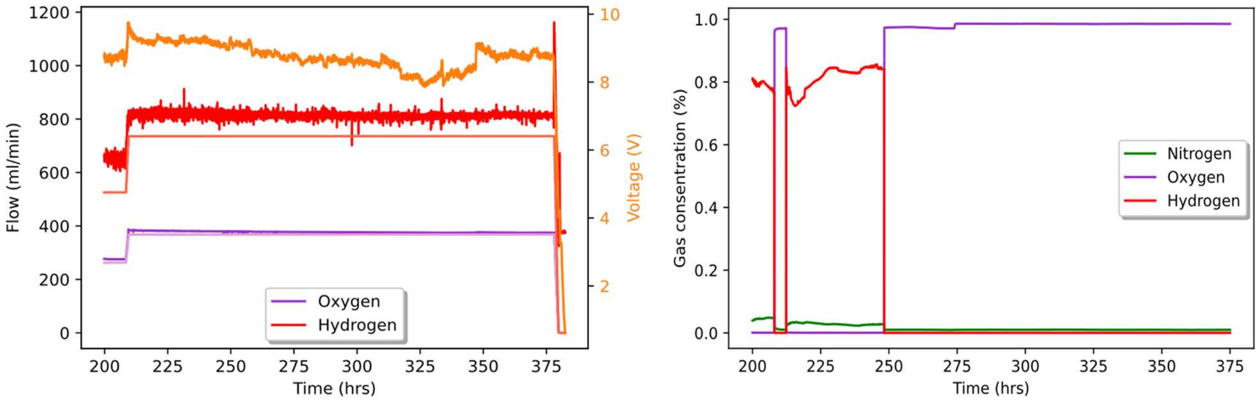

Figure 6. Steady state test data of the Ni/GDC cell. Left: Stack voltage, with produced hydrogen and oxygen amount at constant current (21 A). The overlapping lines represent measured values and expected values calculated from the current. Right: Gas composition (dry) measured by mass spectrometry. first sampled at fuel side, then at the oxygen side.

The breadboard could also be used to generate oxygen at hydrogen at elevated pressure. The maximum pressure reach during the testing was 9 bar [2].

4: Conclusion

The project has demonstrated high temperature electrolysis at elevated pressure up to 9 bar in a bread board at TRL 4. This also includes first time demonstration using LSCrFe fuel electrodes and operation up to 9 bar. If these electrodes are the best option for a real mission, or if a terrestrial stack with traditional materials is a better option cannot yet be fully concluded.

5: References

[1] S. Balomenou, K. Papazisi, D. Tsiplakides "Ceramic Fuel Electrodes for Reversible Solid Oxide Cells Operating on Carbon Dioxide," ECS Meeting Abstracts MA2017-03, pp. 292, July 2017.

[2] N. Thambiraj, I. Wærnhus *et al.* "High Pressure Water Electrolyser Development for Space Exploration Surface Missions," 15th European SOFC & SOE Forum (A1613), July 2022