INNOVATIVE H2 COMPRESSION

Project No.: 736122
Project acronym: COSMHYC

Project title:

COmbined hybrid Solution of Metal Hydride and mechanical Compressors for decentralised energy storage and refuelling stations

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Deliverable 3.5
Report on the tests of the compressive reactor

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Introduction

The COSMHYC project aims at developing a hybrid compression concept based on metal hydrides combined with a mechanical compressor, combining advantages of both technologies to supply hydrogen at very high pressure with an optimized design and energy consumption.

Following the design and fabrication phases realized by MAHYTEC in WP3, a metal hydride reactor has been tested at EIFER. This deliverable presents the testing results of the metal hydride reactor.

This report has been documented and validated at EIFER under the reference: HN-43/21/003.

Disclaimer

1. Introduction and Objectives of the deliverable

The COSMHYC project aims at developing a hybrid compression concept based on metal hydrides combined with a mechanical compressor, combining advantages of both technologies to supply hydrogen at very high pressure with an optimized design and energy consumption.

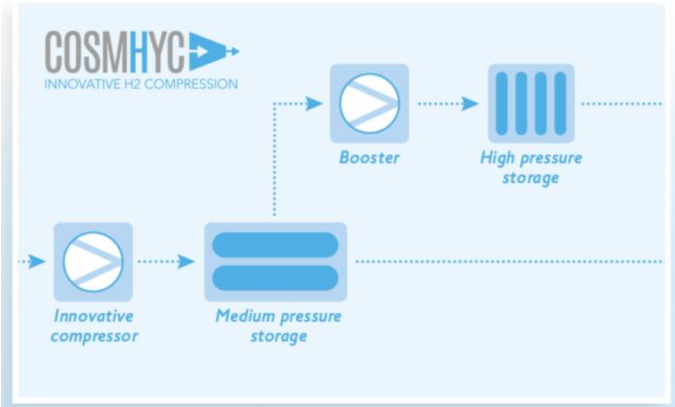

Figure 1- Concept of COSMHYC

In the frame of the work package 3, the aims are to design, develop and test the metal hydride reactors. The design and the fabrication of metal hydride reactors have been performed by the partners based on the expected performance of the different compression stages. These metal hydride reactors do have a particularity: they do not contain any rare earth material. The working principle of this technology is based on the heat management of the system, which allow absorbing hydrogen at low pressure and desorbing it at higher pressure.

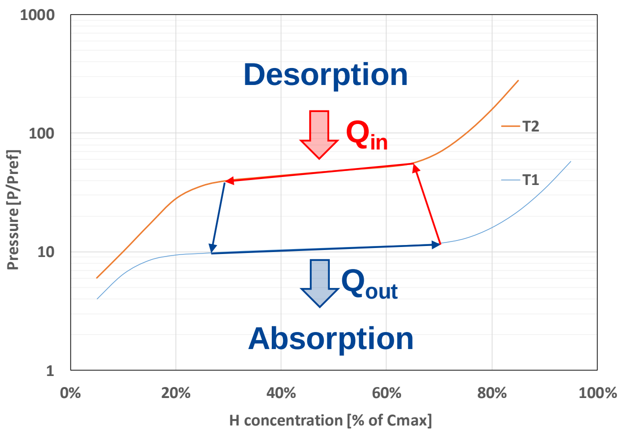

Figure 2- Working principle of metal hydride compression

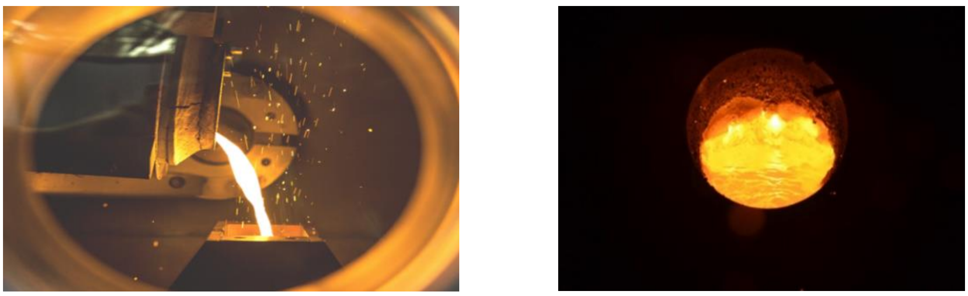

Figure 3- Fabrication process of metal hydrides

This deliverable aims at presenting the tests performed at EIFER with one metal hydride reactor.

2. Presentation of the test bench

EIFER has several test benches in its laboratories that allow performing tests with hydrogen at high pressure in safe conditions. One of them has been adapted for the needs of T3.3, especially for considering specific thermal constraints.

The test bench illustrated in *Figure 4* is composed of:

- A support for metal hydride reactor
- The heat management system (heater, pumps, connection with cooling water, etc.)
- Measuring instruments (pressures, temperatures, gas and fluids flowrates, electrical power)
- Safety components (safety valves, ventilation system, gas detector, etc.)

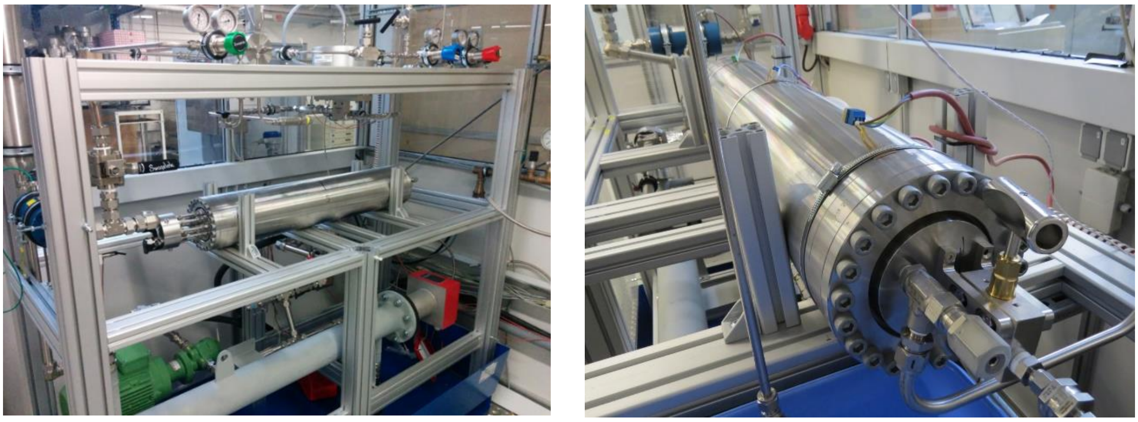

Figure 4- Test bench at EIFER for metal hydride reactors

The test bench is equipped with several sensors and a monitoring system connected to a computer. The data can be observed with LabVIEW, with a dedicated interface. This one is also used to operate the test bench by operating the devices (pumps, heater, valves) and fixing the settings (temperature, pressure).

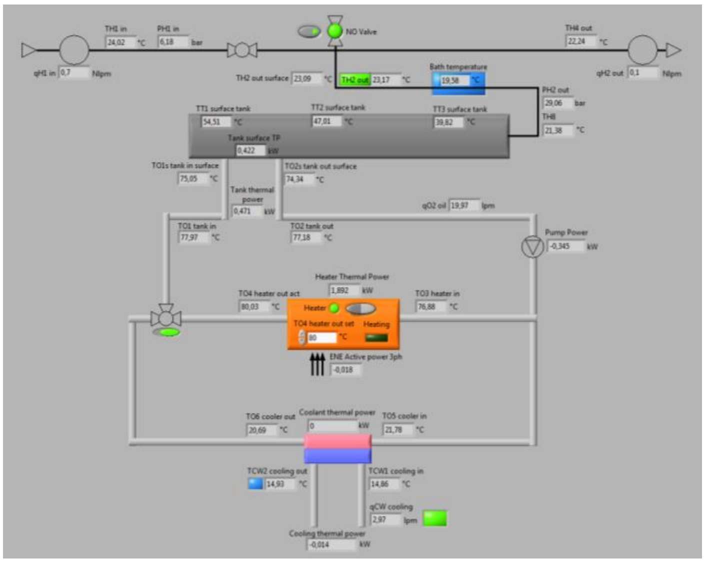

Figure 5- Labview interface

3. Commissioning procedure

The metal hydride reactor was designed, built, certified and mounted on the test bench. According to the German legislation *Betriebssicherheitsverordnung §27: Prüfungen von Druckanlagen vor Inbetriebnahme und nach prüfpflichtigen Änderungen*, the installation had to be approved by an inspection body (in this case, TÜV SÜD), before the commissioning.

To this end, a tightness is required to ensure that the test can be done in a safety way. The procedure included tests first with nitrogen to check every fitting with liquid leak detector, and then with hydrogen. The installation is divided in two zones, respectively for low and high pressure. The installation has been certified in Mai 2019.

4. Test and results

The test performed aims at validating the performance of the metal hydride reactor, in term of pressure/temperature cycling, capacity and safety of operation. The results have been used in WP4 for the design of the compressor and the control strategy implemented.
The following table summarizes the main test results:

Table 1- Main results of the tests

Parameter	Value
Number of tests performed	12
Number of testing hours	~80
Min. input pressure	2,5 bar
Max. input pressure	30 bar
Maximal compression ratio observed	~35 from 2,5 bar, >10 from 20 bar

4.1 Slow cycles

Aim of these tests is to correlate temperature and pressure, by supplying low pressure hydrogen at the reactor inlet and by increasing gradually the temperature.

Table 2- Test matrix - Slow cycles

Test n°	Inlet pressure	Outlet pressure targeted	Tank temperature during absorption
1	2,5 bar	200 bar	~20 °C
2	5 bar	200 bar	~20 °C
3	10 bar	200 bar	~20 °C
4	20 bar	200 bar	~20 °C
5	30 bar	200 bar	~20 °C

Significant improvements of the pressure ratios compared to the state of art were demonstrated and are illustrated in Figure 6:

- The metal hydrides seem to be very reactive to the temperature changes;
- The ability of operating one stage from 20 bar to 200 bar was demonstrated;
- Compression ratio up to ~35 have been reached with only one compression stage, and from very low pressure (2,5 bar). **This result is extremely promising as it is much better than what is typically observed in mechanical compressors** (compression ratios typically between 4 & 6 for 1 stage)

It has to be noted that both curves with 20 bar and 30 bar inlet pressure could even go higher. But due to limitation of the tank, the maximal allowed operating pressure for the tests was ~200 bar. For that reason, hydrogen was simply released when this pressure value was reached.

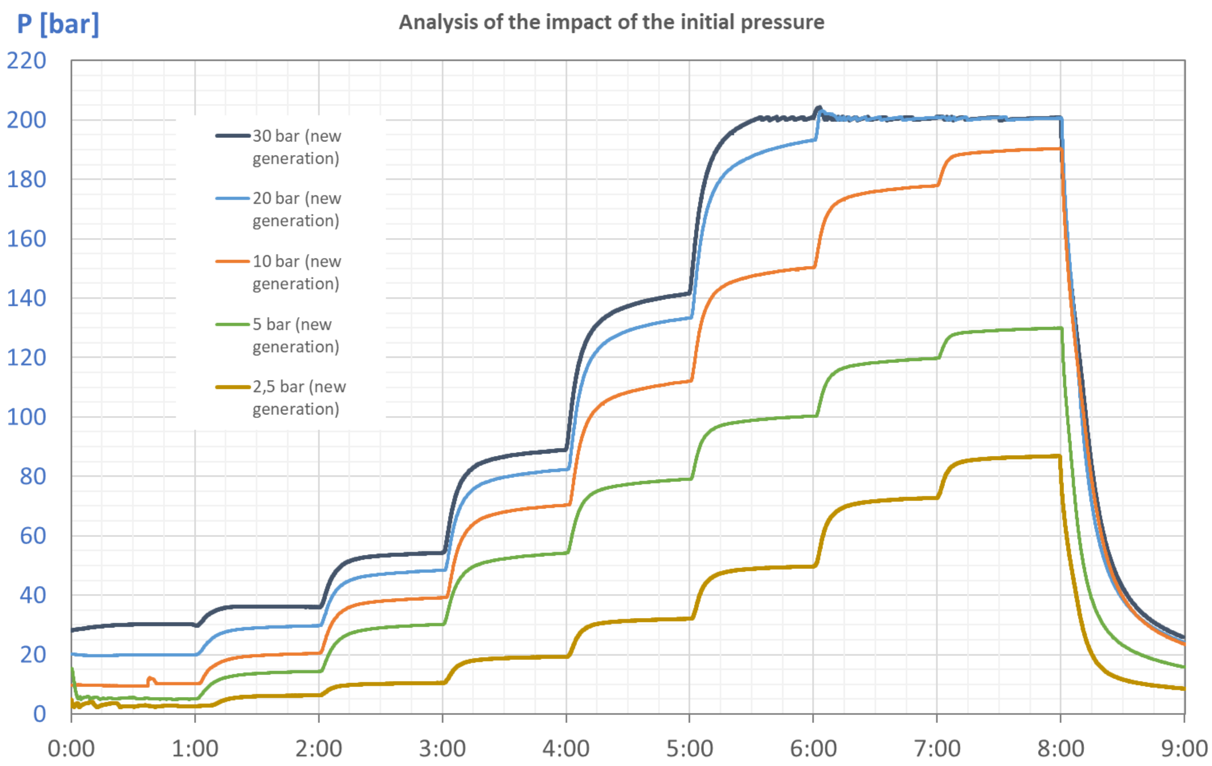

Figure 6- Pressure increase over time while heating the tank

4.2 Tank capacity

Aim of these tests is to analyse the compression capacity of the reactor. For that, the metal hydride reactor is first charged with hydrogen at low pressure, then the temperature is increased until targeted pressure is reached and desorption takes place. Each test is composed of two absorption/desorption cycles, to observe the inertia from cooling phase.

Table 3- Test matrix - Tank capacity

Test n°	Inlet pressure	Outlet pressure targeted	Tank temperature during absorption
6	10 bar	100 bar	~20 °C
7	20 bar	100 bar	~20 °C
8	30 bar	100 bar	~20 °C
9	20 bar	150 bar	~20 °C

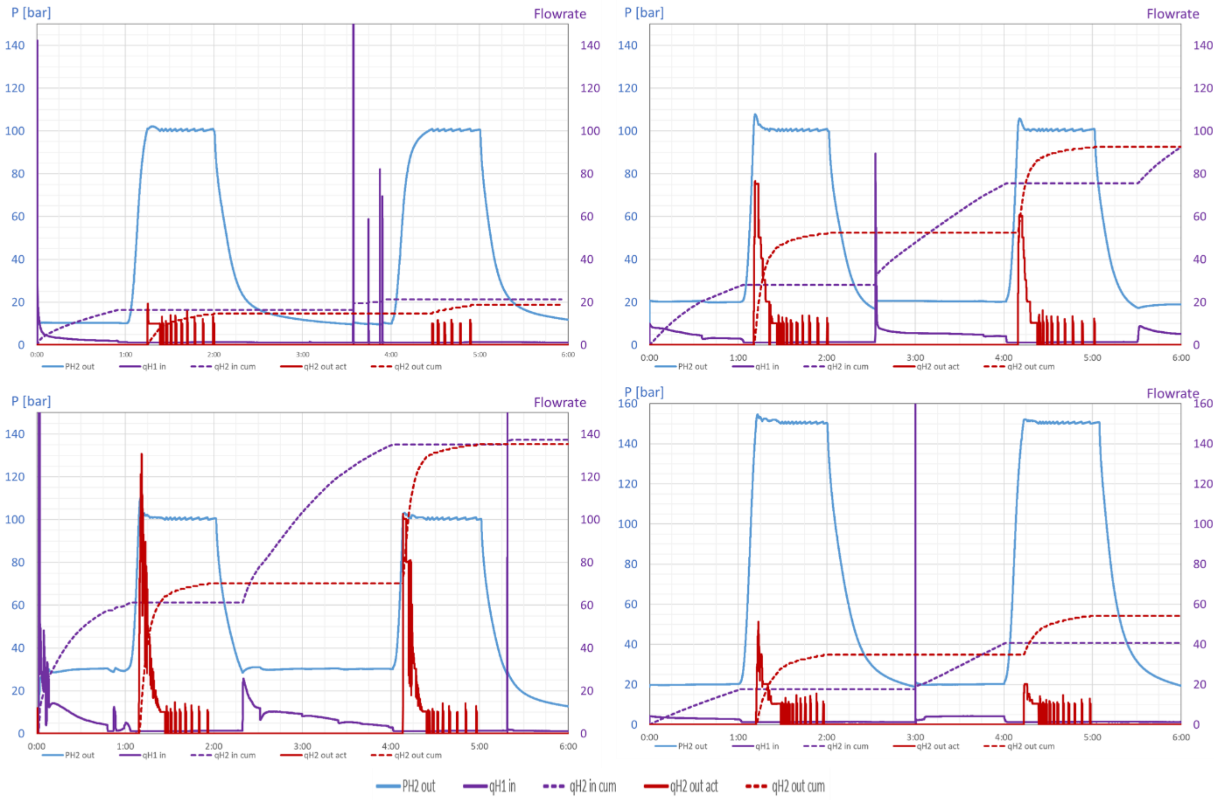

Figure 7- Test results for the analysis of tank capacity (from left to right, top to bottom: tests n°6/7/8/9)

Tests n°6/7/8 show a clear influence of the supplied pressure (at the inlet of the reactor) on the capacity: the latest (after two cycles) is reduced by ~30% (~80%) when the inlet pressure varies from 30 bar to 20 bar (10 bar). However, the capacity decrease with the lower inlet pressure is a normal phenomenon that also occurs with mechanical compressor, where the hydrogen density has a very important impact on the volume of gas compressed by rotational cycle (and also on the volumetric efficiency). At the end, the capacity decrease of the metal hydride reactor seems to be less impacted by the inlet pressure reduction than for typical mechanical compressor, according to data from industrial manufacturers. Test n°7/9 were done to analyze the influence of the outlet pressure. Similar to mechanical compressor, the direct impact of the pressure ratio variation is observed.

One additional interesting information obtained with those tests is the profile of the capacity curve during desorption. Once the targeted pressure is reached, a peak for the flowrate is instantaneously observed for each case, meaning that ~70% of the desorption occurs at the beginning of the discharge phase. The cumulative flowrate shows an asymptote after that and illustrates perfectly this result. This observation provides a relevant input for the control strategy of the compressor, and more particularly for the desorption time setting. Since the desorption of hydrogen is not constant over time, but has a peak at the beginning of the phase and decreases thereafter, one option to increase the overall capacity of the metal hydride compression would consist in reducing the desorption time. In that way, the number of absorption/desorption cycles in a given period of time would increase, resulting in more hydrogen volumes compressed. This is interesting when the target is to optimize the CAPEX of the compression in regard to capacity constraints.

Nevertheless, the main drawback of this strategy would consist in the higher specific energy consumption. The cycling principle requires energy to heat up the metal hydride reactors after absorption, to increase the pressure before desorbing. By reducing the desorption time, the quantity of hydrogen released per cycle is then smaller, but the energy used for heating up remains the same.

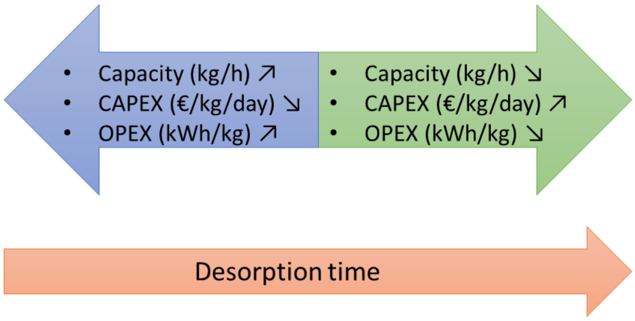

Figure 8- Control strategy for CAPEX/OPEX optimization

Finally, the last observation made concerns the capacity decrease between the first and the second cycles, as illustrated in Figure 9. For each test, the first cycle occurred at the beginning of the day, so that the temperature of the metal hydrides was at room temperature. The operating conditions for the second cycles were different in the way that the cooling between both cycles didn't allow to cool down enough the hydrides: this results to a lower absorption (and then desorption) capacity. To optimize the performances of the metal hydride compressor, the need of an efficient heat management for cooling is a priority to guaranty the lower possible temperature during absorption. Therefore, the main result is that the heat exchange with hydrides is the most important factor for improving the efficiency of the compressor, which justifies the strategy adopted in COSMHYC to dedicate special attention to the thermal integration of the prototype (investigated in WP4).

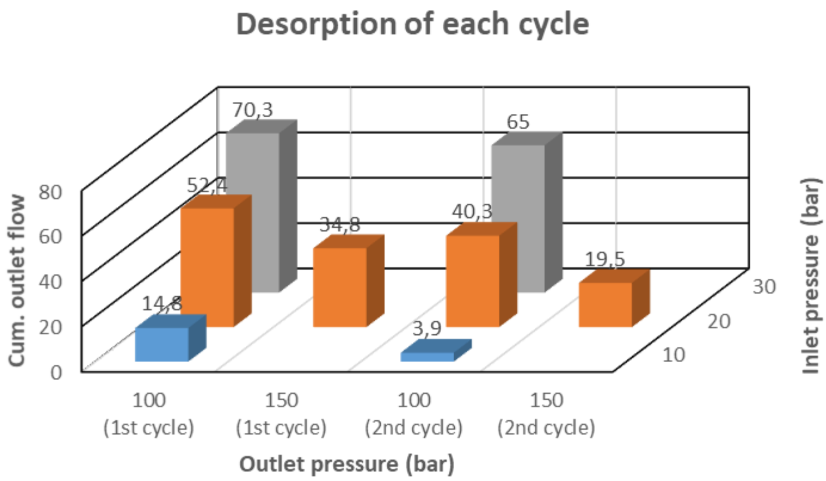

Figure 9- Evolution of the capacity with the number of cycles

4.3 Impact of the absorption temperature

Aim of these tests is to observe the impact of the tank temperature during absorption on the performances of the compression. These tests have been performed with 20 bar inlet pressure, 100 bar outlet pressure, for three absorption temperatures: 20°C, 30°C and 40°C. Both absorption and desorption phases last ~1 hour.

Table 4- Test matrix - Absorption temperature

Test n°	Inlet pressure	Outlet pressure targeted	Tank temperature during absorption
10	20 bar	100 bar	~20 °C
11	20 bar	100 bar	~30 °C
12	20 bar	100 bar	~40 °C

The following observation can be illustrated in Figure 10:

- The targeted outlet pressure (100 bar) is reached in each test;
- The absorption temperature does clearly influence the capacity of the metal hydride reactor. Indeed, the cycle capacity is reduced by ~40% (~60%) by increasing the absorption temperature from 20°C to 30°C (40°C).
- The lower the cooling temperature, the faster the absorption occurs after a compression cycle. The cooling temperature is also a key parameter for the kinetic of the reaction.

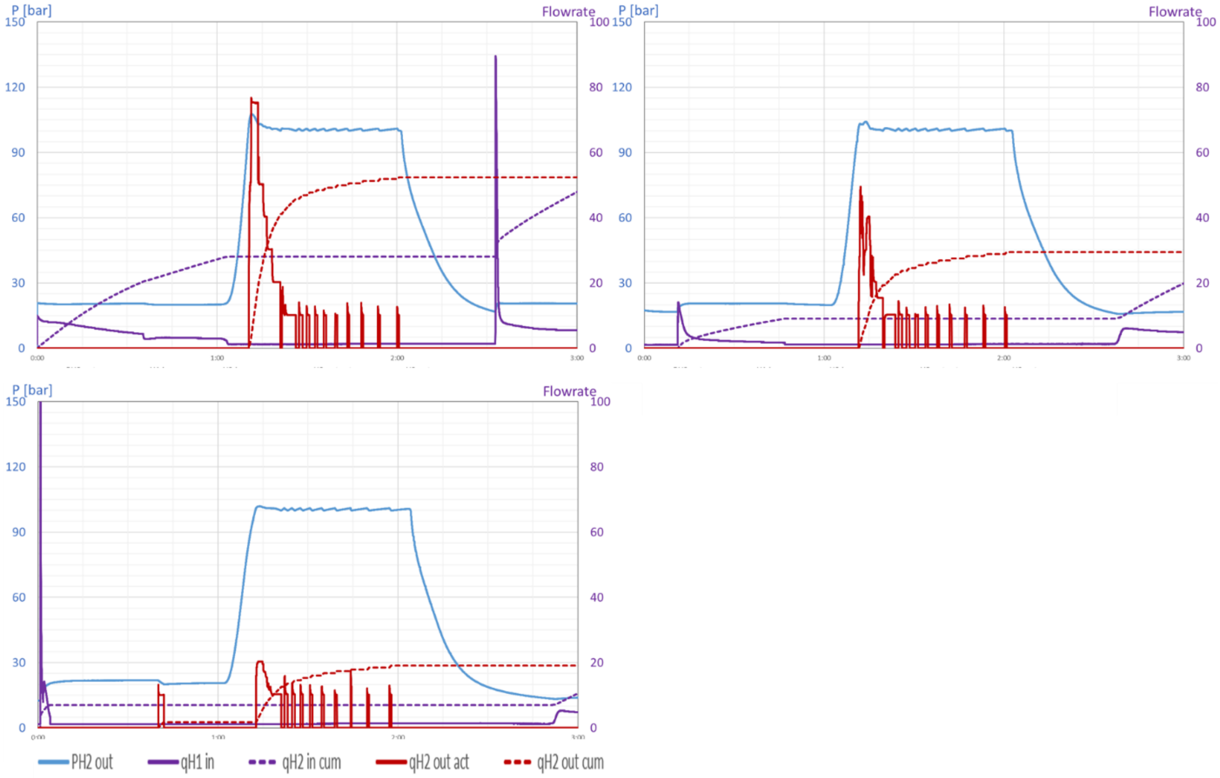

Figure 10- Impact on the temperature for absorption (from left to right, top to bottom: tests n°10/11/12)

5. Conclusions

In the frame of the first phase of the COMSHYC project, extensive investigations took place on a metal hydride reactor filled with innovative hydrides, to validate the techno-economic pertinence of this concept for hydrogen compression. The main findings of these investigations were the following:

- The consortium successfully managed to develop rare earth free hydrides with similar performances as rare earth based hydrides.
- The compression ratios obtained can reach up to 35 for 1 stage, which is far better than the state-of-the-art of mechanical compressors.
- The absorption pressure plays a key role in the capacity of the compressor. This is comparable to what would be observed with a mechanical compressor. This speaks in favour of developing hydrogen production technologies (e.g. electrolysers of pyrogaseification systems) that are able to provide hydrogen under pressure (i.e. 30 bar or more) as this enables to strongly reduce the CAPEX of the compressors.
- There is a strong potential for techno-economic optimisation in determining the optimal compression cycling time. This will be further investigated within the long-term tests of the COSMHYC prototype and in follow-up projects, including COMSHYC XL.