COSMHYC
INNOVATIVE H2 COMPRESSION

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Project acronym: COSMHYC

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

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Public report on the metal hydride compressor

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Deliverable Author	Antoine Jeanmougin
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Introduction

The COSMHYC project aims at developing a hybrid compression concept based on metal hydrides combined with a mechanical compressor. In the frame of the work package 4, the aims were to design, develop and test the metal hydride compressor, based on the hydride reactors developed in WP3.

EIFER designed the compressor in close relationship with MAHYTEC, considering the characteristics of the hydride reactors. The final result is the complete compressor, with all the components integrated. In this deliverable, the work realized in WP4 is presented. This report includes a presentation of the metal hydride compressor, with the description of the core technology used, its main features, its performance as well as selected pictures and illustrations. This report has been documented and validated at EIFER under the reference: HN-43/21/007.

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1. Introduction and Context

1.1 Presentation of the COSMHYC project

The COSMHYC project aims at developing a hybrid compression concept based on metal hydrides combined with a mechanical compressor. This concept combines the advantages of both technologies to compress hydrogen from low pressure up to very high pressure (typically up to 1000 bar for mobility applications). Figure 1 illustrates the concept of the COSMHYC project, with the metal hydride compressor working in baseload, the role of which is to compress hydrogen up to an intermediate pressure (450 bar), and the mechanical compressor for peak demand at very high pressure.

The compression based on metal hydrides is very promising to compress hydrogen from low pressure. As there is no moving part in the hydrogen part of the compressor, the noise disturbance can be significantly reduced, as well as the need for maintenance operations. The use of heat instead of electricity for the compression is very interesting for coupling with a heat recovery system, to increase the electrical efficiency. On the other hand, the mechanical compressor, when supplied with high inlet pressure, is very efficient, shows a limited electricity consumption, can compress hydrogen up to very high pressure with a high flow rate.

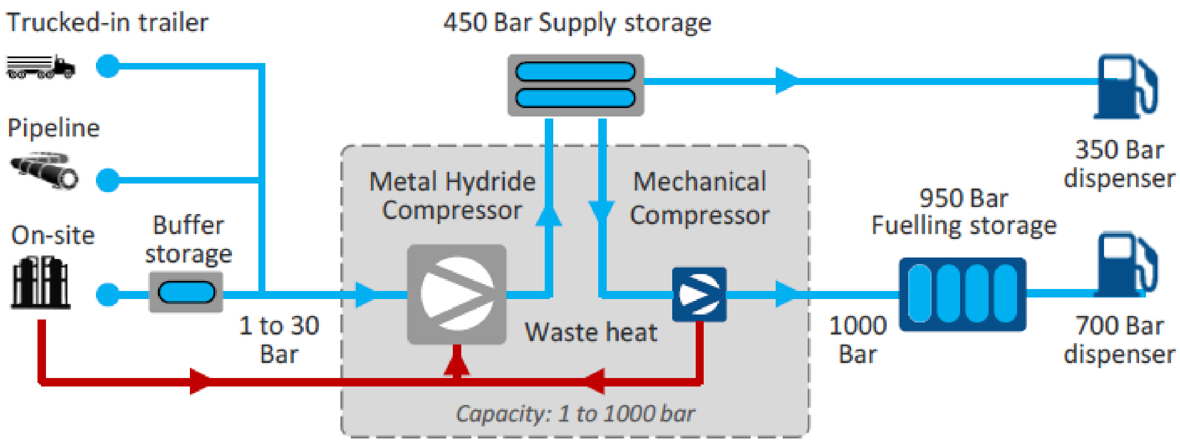


Figure 1- Concept COSMHYC project

Main objective of the COSMHYC project is to demonstrate the potential of both technologies, to investigate their integration and increase the level of TRL from 3 to 5 to prepare market introduction. For this, increasing the efficiency and decreasing the costs compared to the state-of-the-art are the main challenges.

Within the COSMHYC project, the Work Package 4 (WP4) was dedicated to the design (including the specifications of the monitoring and control system) and the construction of the metal hydride compressor. Laboratory tests of the compressor have also been performed to validate the operation of the compressor.

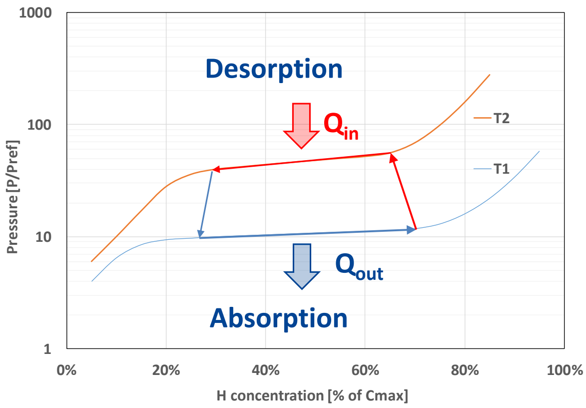
1.2 Working principle of metal hydride compressor (MHC)

The main thermodynamic principle of metal hydride compression utilizes a reversible, heat driven interaction between a hydride-forming metal alloy, or intermetallic compound, and hydrogen gas, to form a metal hydride. It can be summarized by the equation below:

$$M(s) + \frac{x}{2} H_2 \Leftrightarrow MH_x(s) + Heat$$

Where M is a metal alloy and MH_x is a metal hydride.

The equilibrium of the reaction is characterized by an interrelation between the temperature, the pressure and the concentration of hydrogen in the metal alloy. In particular, when hydrogen is absorbed in the metal alloy at a low temperature and a low pressure, the fact to provide heat at a higher temperature enables to release the hydrogen at a higher pressure, producing a compression effect. The simplified principle of a single compression stage is illustrated on Figure 2.



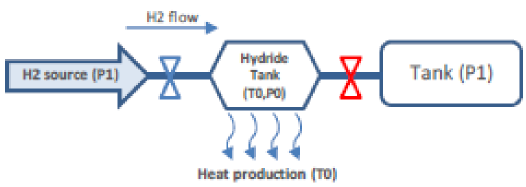
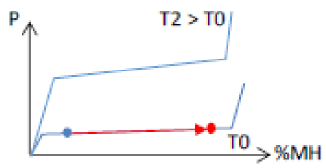
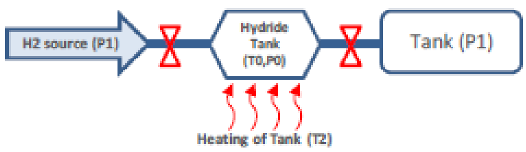
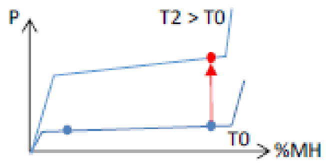
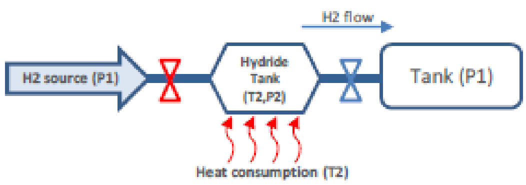
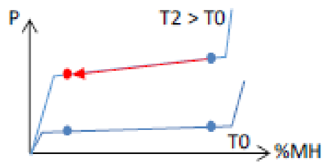
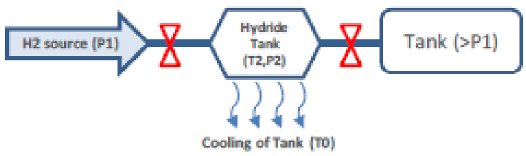
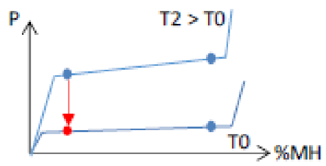
Compression phases	Behaviour of the tank	P, T and hydride concentration (%MH) in Tank
Phase 1 : Absorption		
Phase 2 : Heating		
Phase 3 : Desorption		
Phase 4 : Cooling		

Figure 2- Thermodynamic principle of the metal hydride compression (source: MAHYTEC & EIFER)

2. Presentation of the metal hydride compressor

2.1 General information

The COSMHYC-MHC is designed for an integration in mobility applications with hydrogen production on-site (e.g. electrolysis process) and is adapted for low inlet pressures (10~30 bar). It is composed of two compression stages to reach an output pressure of 450 bar and supply the mechanical compressor. Design compressed hydrogen flowrate is 2 kg/h.

Its integration inside a 20” container is compact and includes the metal hydride reactors, the hydrogen integration (valves, pipes, monitoring & control, etc.) and the thermal integration required for the operation (cooling & heating).

Figure 3- COSMHYC Metal Hydride Compressor

2.2 Metal hydride reactors

The design for the metal hydride reactors and their construction were performed in the frame of WP3.

2.3 Design & Integration

The design of the heating/cooling circuit was performed, based on thermodynamics calculations and the metal hydrides characteristics.

The components were selected according to thermal needs and mechanical calculation of tensions and deformations including all the heavy components and their position inside the container. For this, 3D design and dedicated tools have been used to confirm the stability of the design, as illustrated in Figure 4. Particular attention has been paid for the influence of the racks (containing the metal hydride reactors) and the dry cooler positioned on the roof.

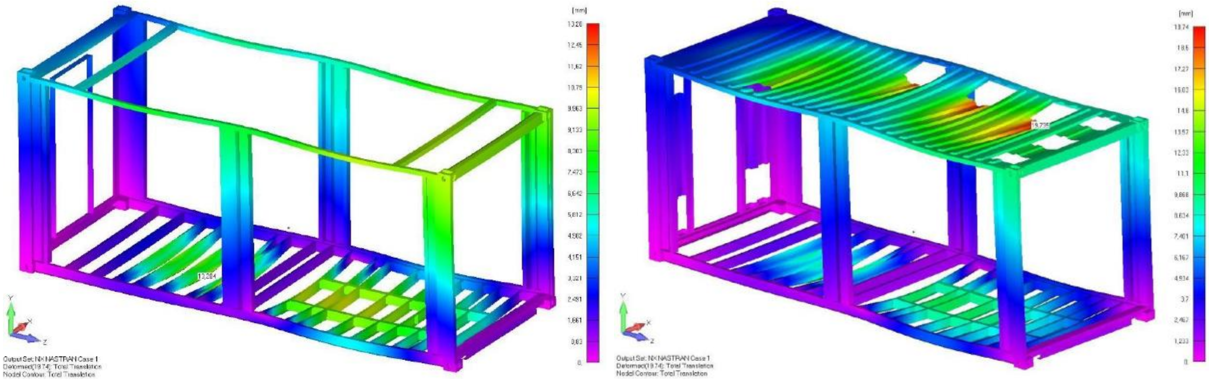


Figure 4- Deformation of the container structure

The safety aspects of the design have been validated through HAZOP and ATEX studies to take into account all possible risks and mitigate them by applying recommendations.

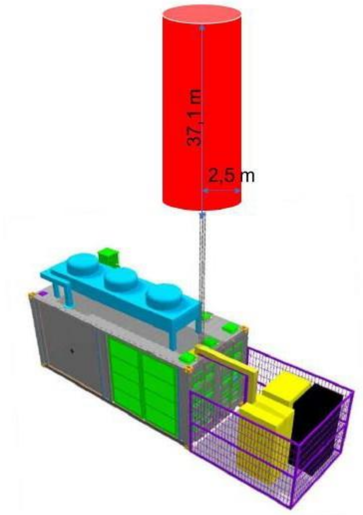


Figure 5- Schematic presentation of ATEX Zone 2 around the vent lines

A monitoring system has been developed by EIFER to ensure data acquisition and to provide the information to the EIFER Webserver for analyzing the data. In addition, a controller (Siemens PLC) has been programmed to operate the MHC, both for manual and automatic modes. However, no safety relevant procedure relay on the controller. The safety approach is based on the integration of specific safety box, which controls the gas sensors, safety temperature limiters, ventilation and other safety relevant devices.

Figure 6- Controller (PLC) in the control cabinet (left) and Human-Machine-Interface (right)

2.4 Construction

The construction of the MHC has been divided in two phases:

- The assembly of components at EIFER laboratory (FCTestLab), typically for gas panel, thermal system and monitoring/control systems;
- The installation on the test site of all components within the container.

The test site at the Fraunhofer ICT facilities (in Germany) provides the electrical connection (100 kW) and necessary gases (compressed air, nitrogen and hydrogen for the tests). Around the MHC container, the test stand is equipped with pressure sensors, pressure reducers and a flow controller to simulate the consumption of hydrogen and recirculate it.

Figure 7- Test site (left) & Main entrance of the compressor (right)

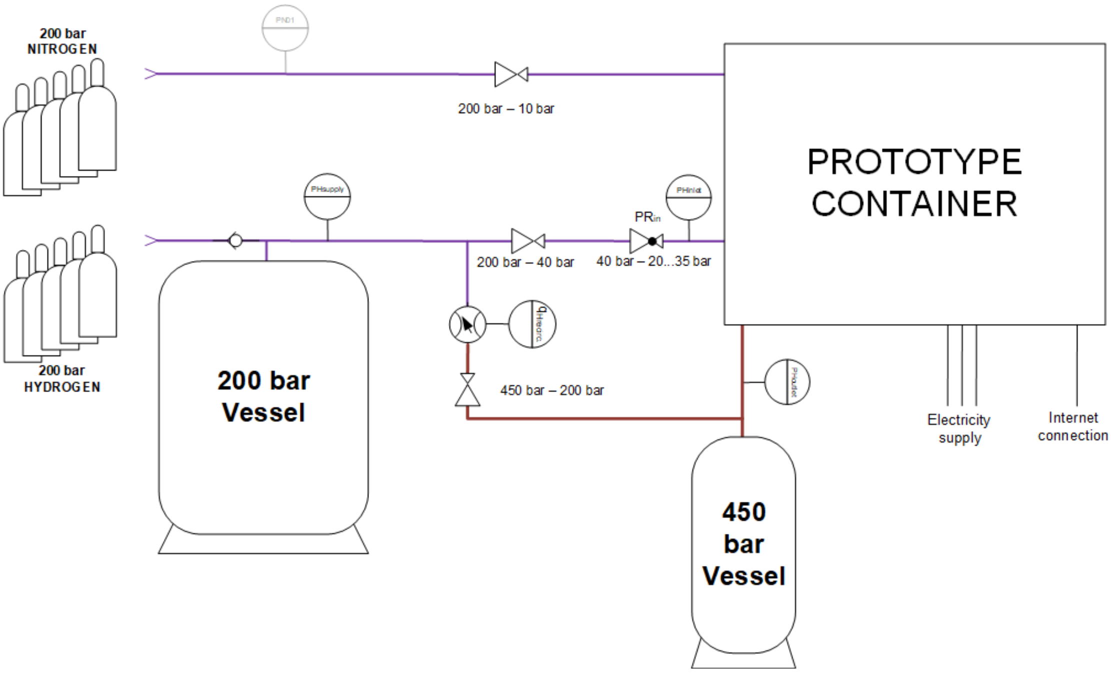


Figure 8- P&ID of the installation for tests

3. Commissioning & test results

Several tests have been performed during the commissioning of the MHC to validate the correct operation of the system. First, the control system was tested to check that every function has been correctly implemented within the controller. Pressure test with nitrogen and hydrogen have also been performed before getting the TÜV approval.

3.1 Pressure levels step and pressure cycling

The metal hydride compressor prototype consists of two stages, with a target to enable a compression from ~30 bar to ~450 bar. The following compression ratios were observed during the test phase:

- Stage 1 proved to be able to compress hydrogen from 28 bar to 112 bar
- Stage 2 proved to be able to compress hydrogen from 97 bar to 429 bar.

Stage 2 could compress hydrogen at higher pressure but the compression ratio was limited by the control strategy of the prototype for safety reasons: due to the fast kinetics of the prototype, it was feared that a pressure above 450 bar could be reached if the compression set point was too close to 450 bar, causing safety valves to open and release large amounts of hydrogen in the atmosphere. Therefore the maximal operating set point was defined at 430 bar.

Figure 9 illustrates the absorption/desorption cycles for both stages, confirming the ability of each stage to perform compression and deliver hydrogen at high pressure.

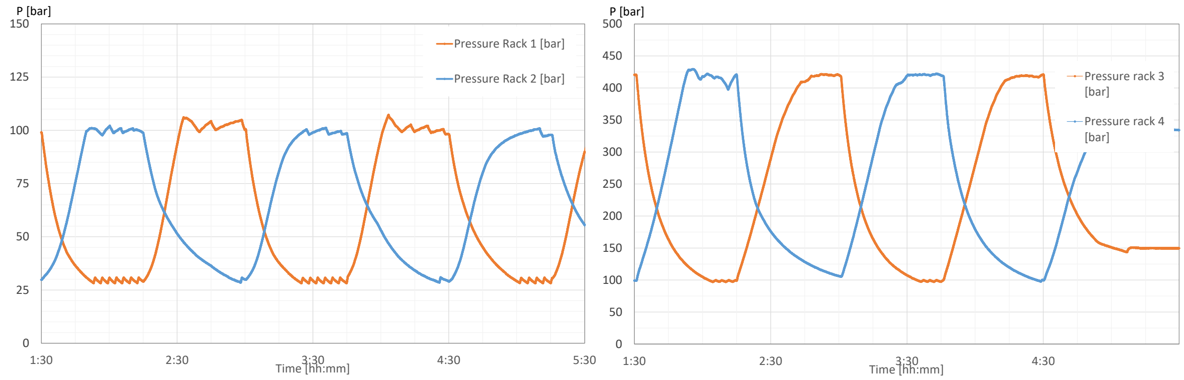


Figure 9-Pressure cycling (1st stage -> left ; 2nd stage -> right)

3.2 Noise level

As noise is one of the key parameters, noise test has been performed to validate the specifications, in different working modes:

- Summer mode, with the cooler at maximal working power.
- Winter mode, with the cooler at a lower speed.
- Compressor off

Figure 10 shows the noise levels at 5m of the compressor, (except the value at 270° as the next building is only at a distance of 3m). The average noise level observed at 5m distance is:

- 53,9 dB in summer / day mode
- 50,6 dB in winter / night mode

This is much better than the state-of-art and shows the high potential of the technology to decrease the noise disturbance of a hydrogen refuelling station. In addition, it can be mentioned that most of the remaining noise is due to the ventilation, which would be present anyway in a hydrogen refuelling station for other pieces of equipment. Therefore, the metal hydride compressor causes almost no noise disturbance.

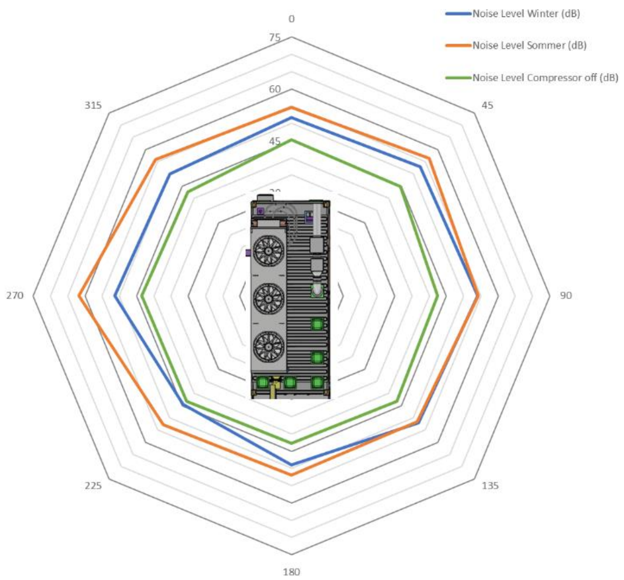


Figure 10: Noise Level of the compressor with different working parameters.

4. Conclusions

In the frame of the COSMHYC project, a prototype of rare earth free metal hydride compressor has been designed, built, installed and commissioned.

- The design of the prototype integration has been successfully achieved based on the specification for the metal hydrides in WP3. Technical choices have been made to optimize the performances.
- The consortium successfully managed to validate all safety related aspects by conducting HAZOP & ATEX studies.
- Integration of the protype and installation took place on the testing facility.
- The monitoring & control systems developed allow to operate the prototype in an automatic mode and to get all the data required for the tests in WP6.
- Commissioning, troubleshooting & preliminary tests have been successfully achieved.
- The prototype successfully reached a hydrogen compression up to 430 bar.
- Almost no compressor specific noise disturbance could be measured, confirming the high potential of the technology for hydrogen refuelling stations in urban areas.