Ref. Ares(2023)5807936 - 25/08/2023

COSMHYC XL
INNOVATIVE H2 COMPRESSION

Project No.: 826182
Project acronym: COSMHYC XL

Project title:

COmbined hybrid Solution of Metal HYdride and mechanical Compressors for eXtra Large scale refuelling stations

Programme: H2020-JTI-FCH-2018-1
Topic: FCH-01-7-2018 - Improvement of innovative compression concepts for large scale transport applications
Start date of project: 01.01.2019
Duration: 54 months

Deliverable 3.6
Public report on the metal hydride reactor tests

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Deliverable Name	Public report on the metal hydride reactor tests
Deliverable Number	3.6
Work Package	3
Completion Date	24.08.2023
Submission Date	24.08.2023
Deliverable Lead Partner	EIFER
Deliverable Author	D. Colomar
Version	**1.1**

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the FCH2 JU Services)	
RE	Restricted to a group specified by the consortium (including the FCH2 JU Services)	
CO	Confidential, only for members of the consortium (including the FCH2 JU Services)	

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Introduction

The COSMHYC-XL project aimed at developing a hybrid compression concept for HRS with a combination of a baseload Metal Hydride Compressor (MHC), enabling a high level of reliability thanks to the absence of moving parts, and a new Mechanical Compressor (MC), enabling very large flow rates.

This document presents information related to the metal hydride reactors and associated tests.

Disclaimer

This report was created within the COSMHYC XL project.

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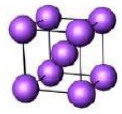
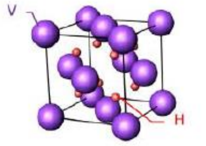
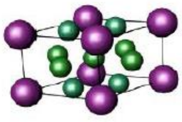
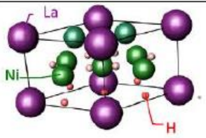
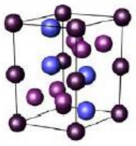
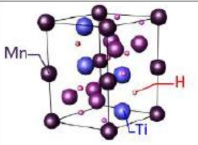
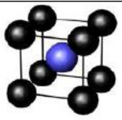
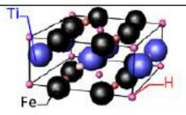
1. Objectives of the deliverable

This deliverable aims at presenting the metal hydride reactors as well as selected results from tests performed by the partners.

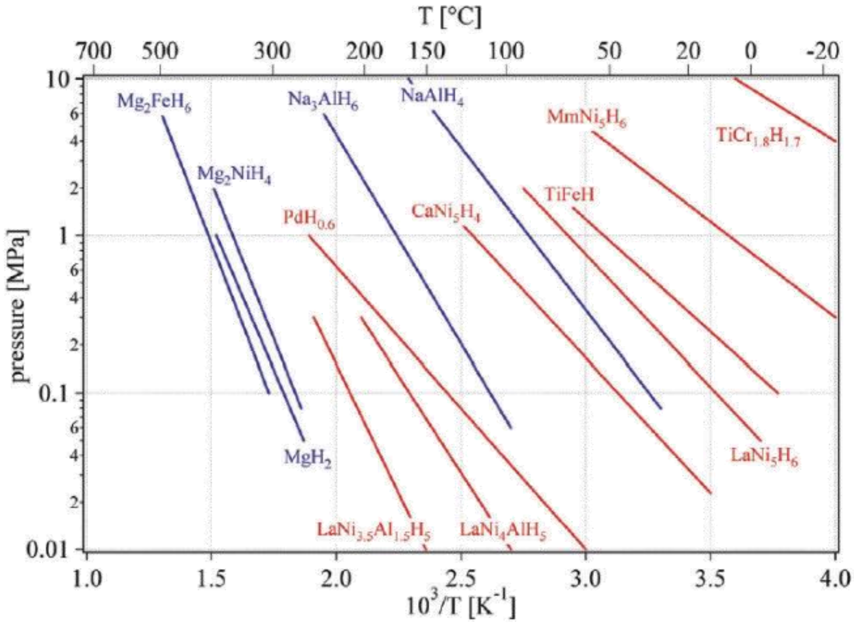
2. Metal hydrides for hydrogen compression

The principle of metal hydride compression is highlighted in the deliverable 5.7. Different families of metal alloys enable to fulfil the requirements of compression, as illustrated below.

Group (representative)	Structure of parent alloy	Structure of hydride	$\Delta V/V_0$ [%]
A (BCC-V)			35.5 ($V \rightarrow VH_2$) 30.9 ($V_2H \rightarrow VH_2$)
B ($LaNi_5$)			20.4 ($LaNi_5 \rightarrow LaNi_5H_6$)
C ($TiMn_2$)			19.6 ($TiMn_2 \rightarrow TiMn_2H_{2.5}$)
D (TiFe)			18.3 ($TiFe \rightarrow TiFeH_2$)

Metal hydride families (Lototskyy, 2014)

Depending on the metal hydride characteristics (as further explained in the deliverable 5.7) a correlation exists between the equilibrium temperature and pressure. Example of these correlations for different hydrides are provided below.



Example of metal alloys with corresponding P/T correlations (Züttel, 2003)

COSMHYC XL partners took into account these correlations and the requirements of mobility applications to select appropriate hydrides.

However, additional parameters had to be taken into account in the selection process:

- **Composition of the hydrides**: it was decided to avoid rare earths in the hydride composition, to reduce the environmental impact, the costs and mitigate the risk of tensions on the resource in future commercial products. This was successfully achieved in the project for selected hydrides.
- **Stability & resistance to impurities:** during the manufacturing process of the hydrides, it was observed that some hydrides presenting in theory a very good P/T ratio for compression were at the end not adapted to the compression use case, either because there were unstable (after a few compression cycles, no more absorption was observed) or because they were highly sensitive to impurities. This later characteristic is of high importance for compression, as the compression operating mode requires high number of cycles. Therefore, even with very pure hydrogen supply, it can be expected that impurities will come in contact with the hydrides. Consequently, the metal alloys selected must show a certain resistance to these impurities.
- **Constraints on activation.** One important lesson learnt from the project is the need to select hydrides with technically feasible operational conditions at scale. In particular, in order to build large-scale hydride reactors, it is important that the hydride can be activated under the same conditions as the conditions of service, especially in terms of temperature. Otherwise, it would be impossible to activate them after filling the tanks. Filling the tanks with pre-activated hydride would represent a strong technical, safety and regulatory challenge.

Hydride samples after preparation are illustrated below.

Example of hydride samples as in COSMHYC XL

3. Metal hydride reactors

Metal hydride reactors were built including metal hydrides to provide the compression functionality. Particular attention had to be paid to the following aspects:

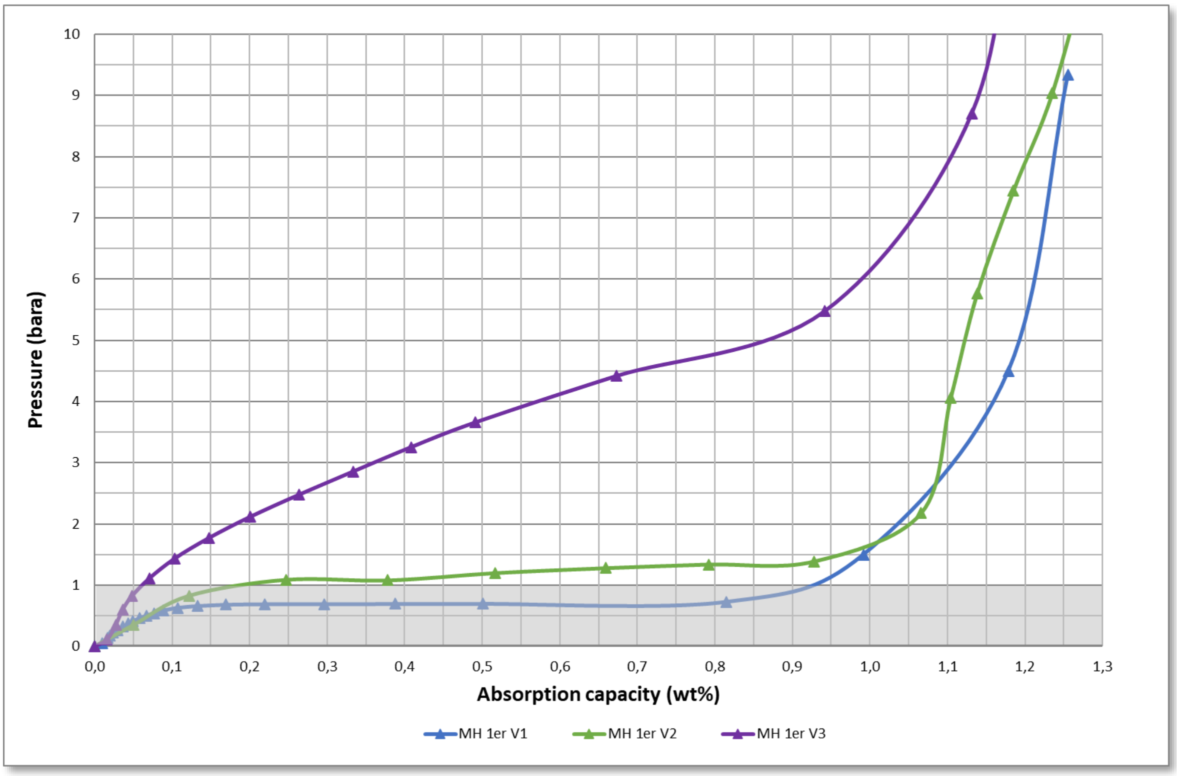
- **Geometrical choices** enabling easy filling and maintenance. This was particularly impacting when designing the neck of the tanks: standard high-pressure bottles include thin necks to minimise the forces applied to the caps. However, this is not feasible the same way for hydrogen compression, as the vessels have to be filled with different components, resulting in strong engineering efforts on the neck design.
- **Thermal efficiency** by guaranteeing sufficient heat exchange with the hydrides while not loosing too much energy. In fact, one important lesson learnt in the project was that the main source of energy loss in the system is due to thermal inefficiencies
- **Weight management:** it was demonstrated that heavy tanks induce significant additional energy losses and constraints in the overall system integration. Therefore, it was important to minimise tank weight, thanks to appropriate geometry and material choices.
- **Safety:** in order to guarantee the safety of the persons and goods and meet certification requirements, attention was paid to prevent tank explosion, H2 & hydride leakage by implementing appropriate safety measures, being the result of dedicated HAZOP studies
- **Reproducibility** to anticipate large-scale systems. This includes specific geometrical choices to match the requirement of standard production processes.

As a whole, 20 different compression vessels at 3 different compression stages were built, as illustrated below.

Metal hydride reactors in COSMHYC XL

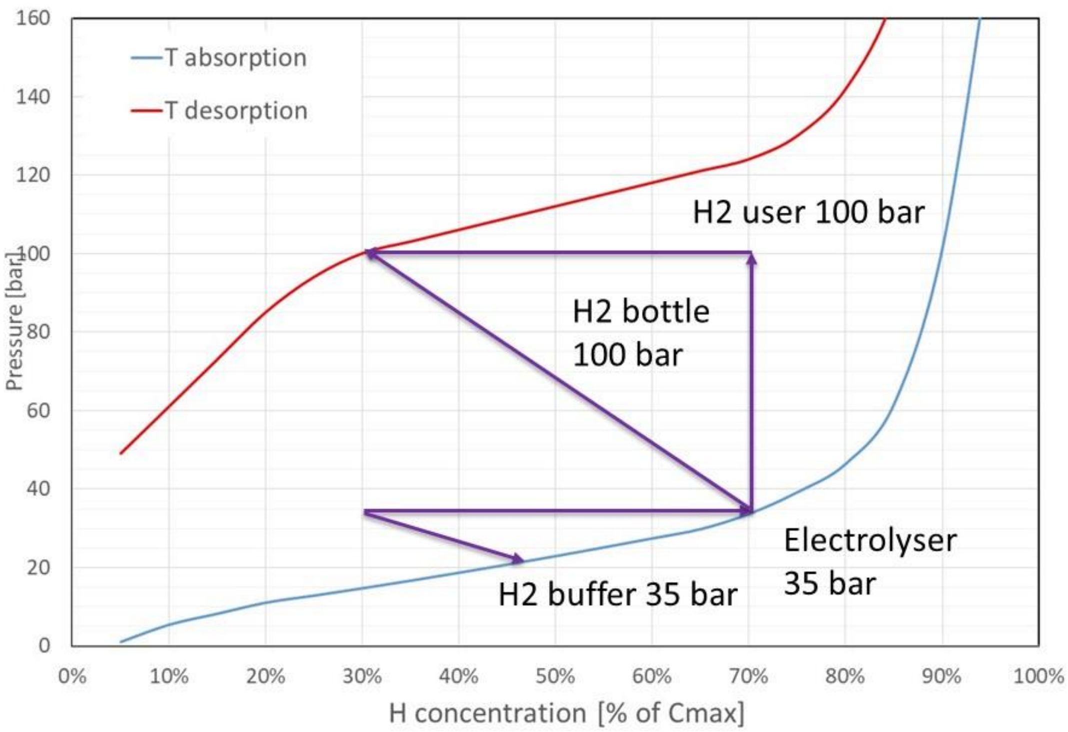
4. PCT

For each of the 3 compression stages, PCT curves were established during the selection and validation process of the hydrides. One important lesson learnt is that, instead of horizontal absorption/desorption plateaux, as expected from the theory, the real metal hydrides developed sometimes showed a slope in the absorption/desorption phase. This slope can be very limited, so that the plateau is almost horizontal, or very high. Examples of PCT realised in COSMHYC XL are provided below.



PCT curves realised within COSMHYC XL

This is an important lesson learnt of the project, as the behaviour of the slope may have different consequences on the compressor profile, depending on the expected use was. As an example, different cycles steps and how they are affected by the slope of the PCT are illustrated below.



Illustrative compression cycle steps depending on use case

5. Test performed on absorption capacity

One important lesson learnt from the project is that the PCT is not sufficient to select alloy composition. It is also important to validate the absorption capacity at each pressure value. An example of absorption capacity test is provided below, in which two alloy candidates were compared.

Absorption capacity tests performed in COSMHYC XL

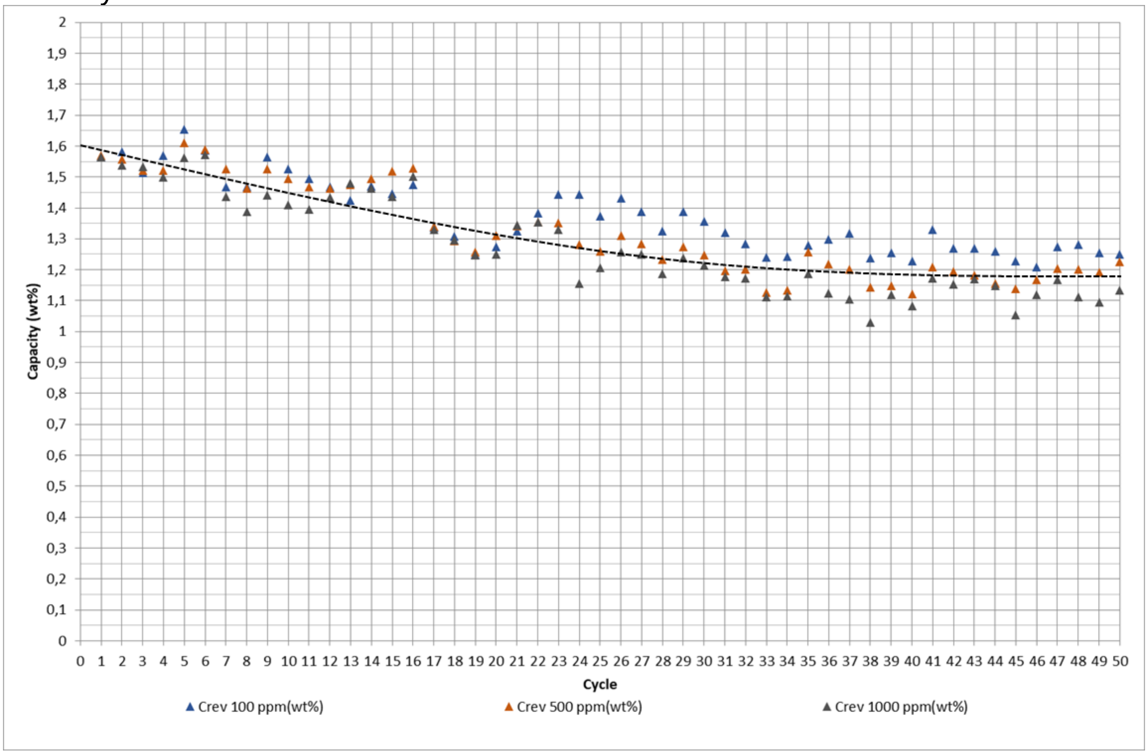
The green and orange bars respectively represent the cumulated desorbed hydrogen in 2 different alloys for different pressures at the same desorption temperature. After having absorbed hydrogen, the hydrides are heated up and the vessel is then opened. Downstream, a pressure regulator is mounted and enables to regulate the pressure. First, the regulator is set at a very high pressure, so that no hydrogen can be released. Then, the pressure is progressively decreased, so that hydrogen start to be released, as soon as the set pressure is lower than the plateau desorption pressure. As can be observed, both hydrides are able to desorb hydrogen at 300 bar. However, the green alloy can only desorb 0.4 w% at this pressure, while the orange one can desorp1.4 w%, which induces a flow rate capacity 3 times better for the same amount of hydrides.

6. Tests performed on resistance to impurities

One important criteria for the commercialisation of metal hydride compressors is to better understand the behaviour of metal hydrides in case of involuntary contact with impurities. For this purpose, the behaviour of metal hydrides with contaminated hydrogen was tested. Several impurities were tested, including water, oxygen, nitrogen carbon dioxide and carbon monoxide.

As expected, it was confirmed that contaminated hydrogen induces degradation of the hydrides as the pollutants fix on the metal alloy particles, preventing hydrogen to come into the metal alloy structure.

However, an interesting lesson learnt from the tests was that **degradation mostly happens at the beginning of the tests**. After a while, the performances of the hydrides stabilise, as if the hydrides were “protected” by a first layer of contaminated alloys. An example of test is provided below: metal alloys were place in contact with contaminated hydrogen and cycles were performed. In each cycle, the amount of hydrogen absorbed and desorbed was measured. Each point represents the measured absorption capacity of one cycle. It can be observed that there is a fast decrease in the performance of the hydride at the beginning, then the performance seems to stabilise despite the presence of impurities. This is a very promising result, as it could mean that even contaminated hydrogen could in some extend be used with metal hydrides.



Test performed on metal hydrides in COSMHYC XL with contaminated hydrogen

7. Overall conclusions

As a whole, various tests were performed in the frame of COSMHYC XL on metal hydrides and metal hydride tanks, enabling to successfully select appropriate hydrides for hydrogen compression and better understand their behavior, thereby paving the way to large-scale pre-commercial demonstration, which will be done in the frame of the follow-up project COSMHYC DEMO.