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Design, development, construction and operation of a novel metal hydride compressor

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ABSTRACT

Metal Hydride Compressors (MHC) is a promising technology for thermal compression of hydrogen. Besides the absence of a necessity for significant mechanical or electrical energy input, this type of compressor has the advantage that no moving parts are involved. A brief review on the reported experimental set ups of metal hydride compressors is carried out and compared to the metal hydride compressor developed and constructed by HYSTORE Technologies Ltd in Cyprus. The compressor built by HYSTORE consists of 6 stages using AB_2 and AB_5 – type metal hydride alloys. The MHC is operated between 10 C and 80 °C, which is a temperature range that can be supplied by solar thermal collectors. Furthermore, the experimental results showed, that even lower temperatures of 17 C are sufficient thus reducing the demand for cooling capacity. During the operation, the compressor achieved stable compression of hydrogen from 7 bar more than 220 bar. The specific productivity of the compressor achieved values up to 67.2 $l_{H2}\ kg^{-1}\ h^{-1}$.

Introduction

Hydrogen compression with metal hydrides in temperature swing operation is a promising component for future hydrogen systems, as they have the capability of compressing hydrogen to high pressures without moving parts and do not require mechanical energy, but only heat. Especially if a waste heat source is available, this can be an advantage of paramount influence on the overall energy balance of a system. Alternatively, in regions with high solar irradiance, solar heat can be used to achieve a reduction in greenhouse gas

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emission. Further advantages that are mentioned in an extensive review article on this topic by Lototskyy et al. [1] from 2014 are compactness, safety and reliability as well as simplicity in design. However, due to high weight, they will most likely be used for stationary applications [2]. Especially solar-thermal processes for hydrogen production usually release substantial amounts of waste heat, such as solar assisted high temperature electrolysis [3], water splitting in thermochemical cycles [4] and solar reforming of natural gas [5,6]. Hence, those processes could be very suitable to be coupled with a metal hydride hydrogen compressor.

The working principle of metal hydride compressors (MHC) is explained in several publications [1,7,8] and briefly reproduced as follows: A reversible reaction is used, where a solid hydride-forming metal/alloy/intermetallic compound (M) reacts with hydrogen to form a metal hydride (MH). When the hydrogen is bound in the metal hydride it is called adsorption, the reverse reaction is called desorption. The adsorption is exothermic, i.e. it releases heat (Q) and is therefore promoted by low temperatures. For desorption, the contrary is the case. The reaction is presented in Eq. (1).

$$M(s) + \frac{x}{2}H_2 \rightleftharpoons MH_x(s) + Q \quad (1)$$

The equilibrium of the reaction is defined by a set of variables, which are the hydrogen pressure (p), the concentration of the hydrogen in the solid (C) and the Temperature (T). Hence, the characteristics of a given material are usually presented in a PCT-diagram. An exemplary PCT-diagram for two different temperatures is showed in Fig. 1, representing the equilibrium hydrogen pressure as a function of hydrogen concentration in the hydride forming alloy. The metal hydride materials have common typical characteristics regarding the change in C with a variation of the pressure. At low hydrogen concentrations in the material ($0 \leq C < a$) the concentration changes with $C(H) \sim \sqrt{p(H_2)}$. For higher concentrations ($a \leq C \leq b$) a plateau pressure evolves, i.e. the equilibrium pressure is nearly constant with concentration. For even higher concentrations ($C > b$), the equilibrium pressure increases asymptotically towards infinite values. The plateau width (b-a) is called the reversible hydrogen capacity. This curve is shifted towards higher pressures for higher temperatures. In metal hydride compressors, this effect is used to compress hydrogen, as shown in Fig. 1. The hydrogen is adsorbed at the lower temperature (black line), in this example until the value of 145 l_{H2}/kg_{MH}. Then it is desorbed at higher temperature (red line) down until the concentration of 15 l_{H2}/kg_{MH}. The amount of hydrogen that is pumped is the mass of metal hydride multiplied with the difference in concentration ΔC, in this example 130 l_{H2}/kg_{MH}.

In Fig. 1, a single stage compression with a metal hydride is shown. It can be seen that the pressure plateau is not actually flat but has a slight slope. This is the case for all real metal hydride systems. With this single metal hydride material shown in the figure, only a periodic operation is possible. In order to allow for continuous operation, two or more containers can be installed in parallel and operated with a phase shift. In order to increase the overall pressure ratio, several MHC stages are set up in series. If this is done, usually different metal hydride materials have to be used for effective compression to high pressures.

HYSTORE Technologies Ltd. developed and operated a six-stage MHC on which will be reported in this article. The aim for the developed MHC was to be able to be operated by solar heating and cooling, i.e. approx. 10 °C low temperature and 80 °C high temperature and achieve an outlet pressure more than 220 bar from an input pressure of 7 bar. Before presenting results of development and operation of the MHC, a brief technology review is given in order to put the presented results into context. Firstly, materials for MHC are briefly discussed; subsequently an overview of the published information on MHC set ups is given. However, for a more extensive review on MHC activities, the 2014 article by Lototskyy et al. [1] is strongly recommended.

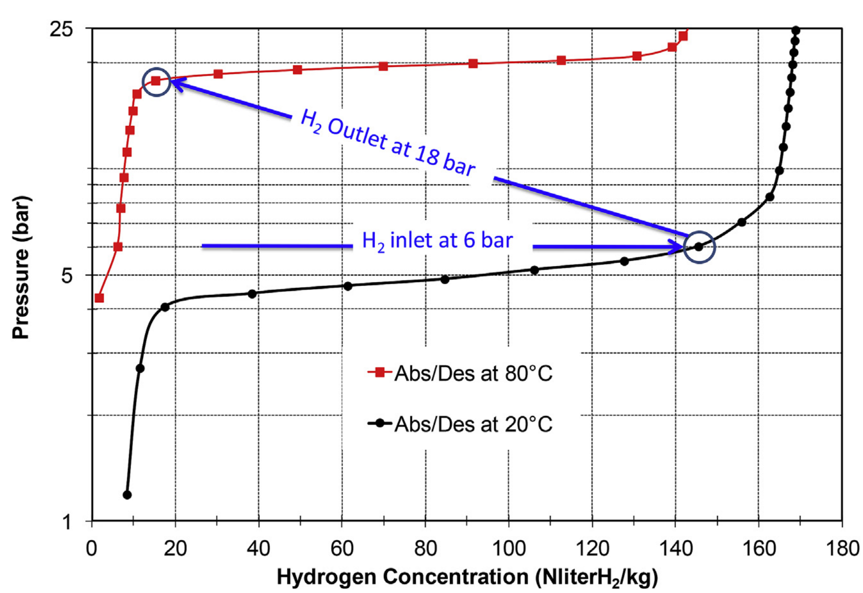

Fig. 1 – Exemplary PCT diagram for hydrogen compression with metal hydride. Actual measurement data for $La_{0.8}Ce_{0.2}Ni_5$.

Materials for MHC

The metal hydride materials are a crucial component in design of a metal hydride compressor, because the PCT curve has to meet the demand of the compression process. Furthermore, in multi-stage compressors, different materials have to be found that can be well connected, i.e. the desorbing pressure of the first stage at the higher temperature has to match the absorbing pressure of the second stage at the lower temperature, the desorbing pressure of the second stage at the higher temperature has to match the desorbing pressure of the third stage at the lower temperature and so forth. Therefore quite some effort has been put into material characterization in the past and is still ongoing.

Lototskyy et al. [1] give a list of requirements that the MH material should fulfill, some of those are:

- PCT characteristics allow a compression from the lower pressure to the required higher pressure at the available temperatures T_L and $T_{H.}$
- The reversible storage capacity of the material should be high in order to reduce the necessary material for a given compression capacity.
- Fast kinetics to reduce the required material for a given compression capacity.
- Low slope of plateau pressure to achieve high compression ratio.
- Low hysteresis to achieve high compression ratio.
- Cycle stability.
- Tolerance on impurities.
- Availability at required scales at affordable costs.

The multitude of available materials for storing hydrogen can be divided into those that only bind the hydrogen by physisorption, which is a weak bond with low heat of reaction (<10 kJ/mol) and those that bind the hydrogen in chemisorption (and bulk absorption), which is a strong bond with high heat of reaction (>10 kJ/mol) [9]. For application in metal hydride compressors usually only materials of the second type are considered. Among these, two well known material types are AB_2 and AB_5 type alloys [1,10]. Lototskyy et al. [1] give a general description of the different material types: They state that AB_5 materials allow suction pressures in the range of 1–30 bar at a lower temperature of 25 C and discharge pressures in the range of 15–200 bar at a higher temperature of 100–150 °C. They furthermore state that AB_2 type alloys can cover a much broader range of pressure. They give some examples of plateau pressures from 10^{-6} mbar to 40 kbar at room temperature for different materials of this type. Furthermore they state that AB_2 types are more sensitive towards poisoning by impurities than AB_5 type alloys. There are several publications available regarding the synthesis and understanding of MH forming alloys (e.g. Ref. [10] for AB_2 materials), but they are usually focused on hydrogen storage rather than compression. Therefore, they usually aim for low plateau pressures of hydrogen. In contrast to that, for application in MHC, the plateau pressures at the lower and higher temperature should match the suction pressure and desired pumping pressure correspondingly. In the list above, among others, fast kinetics for the reaction are stated as a requirement for the material. However, as also stated by Lototskyy et al. [1], the intrinsic kinetics of the material (i.e. not taking into account impediments by overall geometry or material particle size) are sufficiently high but heat transfer into the material bed is low due to low thermal conductivity. Lototskyy et al. [1] also state that usually the thermal conductivity of a metal hydride powder is around 1 W m^{-1} K^{-1}. Therefore, some effort is also being made to quantify and improve the thermal conductivity of suitable metal hydrides. For instance, Madaria and Anil Kumar [11] investigated the improvement of effective thermal conductivity by adding graphite flakes and copper wire mesh structures. They could enhance the thermal conductivity from 1.3 W m^{-1} K^{-1} for the pure powder to 6.8 W m^{-1} K^{-1}. They also assessed the impact of the improvement of thermal conductivity onto the compressor performance and showed significant improvements [8]. However, as can be seen from the reported approaches for improvement, this is rather an aspect that is approached in reactor design than in actual material design.

Past and current R&D activities

Even though the topic of MHC is just a niche application in the wide field of metal hydride application, a number of publications on experimental set ups of metal hydride compressors exists. In Table 1 an overview of the published experimental set ups is given. It can be seen, that the majority of the experimental set ups operated in the range of a few bar to below 100 bar and between ambient temperature and 100–150 C. As already mentioned, the aim of HYSTORE is to pump hydrogen from 6 to 220 bar in a temperature range between 5 °C and 220 °C. Comparing this aim to the literature data presented in Table 1, it can be seen that HYSTORE aims for lower temperature levels than most set ups from literature and aims to achieve high pressures, only the data reported by Vanhanen et al. [12] and Ergenics [13] are comparable. Those MHC applications that had a different focus, such as for instance cryo-coolers for space applications [14] were not included in the Table.

Those projects presented in Table 1, that have a delivery pressure of 100 bar or higher and an upper temperature of 130 °C or below, i.e. are similar to the aim of HYSTORE, are reproduced in Fig. 2. It can be seen that only 6 projects are left, of which one is only a numerical study (Muthukumar et al. [15]). It can be seen that the MHC set up that matches the aims by HYSTORE best is the one by ERGENICS. Especially, regarding the delivery pressure, the work by Kelly and Girdwood [16] is very interesting, but the upper temperature level is significantly higher than what HYSTORE aims for. The data published by Vanhanen is also very similar to the aims of HYSTORE. However the data is only an estimation of the possible maximum pressure, in the experiments they could only show pressures slightly above 100 bar, because they only built 2 of the 3 considered stages.

In Table 1, some commercial or semi-commercial activities are also included (lines with symbol). Besides the already mentioned activity by Ergenics, these are the MHCs produced by HYSTORSYS in Norway (HYMEHC10 and previously the smaller HYMEHC 5) as well as the MHC by SAIAMC/UWC that

Table 1 – Information on published data on metal hydride compressors. References, number of stages, temperatures, pressures and alloys used.

Project	Reference	Number of stages	T_L; T_H in °C	p_{Inlet}; $p_{Delivery}$ in bar	Alloys used
Silva 1993	[17]	1	25; 250	10; 100	FeTi
Shaml'ko 1999	[18]	1	25; 277	15; 400	MmNi5
Ergenics	[13]	6	25; 85	1; 206	Not published
Laurencelle 2009	[19]	3	25; 80	1; 22	S1: LaNi4.8Sn0.2 S2: LaNi5 S3: MmNi4.7Al0.3
Cieslik 2009	[20]	2	37; 177	0.2; 33	S1: LaNi4.25Al0.75 S2: LaNi4.8Sn0.2
Popenciu 2009	[21]	3	20; 80	2; 60	S1: LaNi4.85Al0.15 S2: $LaNi_{4.9}Cu_{0.1}$ S3: $MmNi_{4.05}Fe_{0.95}$
Kim 2008	[22]	1	20; 90	6.9; 40	$LaNi_5$/$LaNi_{4.75}Al_{0.25}$
Muthukumar 2008	[23]	1	25; 95	5; 43	$MmNi_{4.6}Al_{0.4}$ (Sensitivity study on different parameters)
Li 2010	[17]	2	25; 150	40; 740	S1: $La_{0.35}Ce_{0.45}Ca_{0.2}Ni_{4.95}Al_{0.05}$ S2: $Ti_{0.8}Zr_{0.2}Cr_{1.9\text{-}x}Fe_xV_{0.1}$ (x = 0.5; 0.95; 1.1)
Bhuiya 2014	[24]	2 (3 Cases)	10; 125	6.9; 103/138/159 (theory); 55/75/83 (shown)	S1: $LaNi_5$ S2, C1: $LaNi_5$ S2, C2: $Ca_{0.6}Mm_{0.4}Ni_5$ S2, C3: $Ca_{0.2}Mm_{0.8}Ni_5$
Wang 2011	[25]	2	25; 150	30; 700	S1: $Ti_{0.95}Zr_{0.05}Cr_{0.8}Mn_{0.8}V_{0.2}Ni_{0.2}$ S2: $Ti_{0.8}Zr_{0.2}Cr_{0.95}Fe_{0.95}V_{0.1}$
Muthukumar 2012	[15]	3	25; 120	2.5; 100	S1: $LaNi_5$ S2: $MmNi_{4.6}Al_{0.4}$ S3: $Ti_{0.99}Zr_{0.01}V_{0.43}Fe_{0.99}Cr_{0.05}Mn_{1.5}$ (Only a numerical study)
Endo 2016	[26]	1	25; 60	2; 5.3	$LaNi_5$
Lototskyy 2009	[27]	2	25; 130	7; 200	S1: (La,Ce)Ni5 S2: (Ti,Zr)(Cr,Fe,Mn)2
Lototksyy 2012	[28]	2	25; 130	10; 200	S1: AB5 S2: AB2 (Not specified)
Madaria 2016	[8]	1	25; 80	10; 35	$La_{0.8}$;$Ce_{0.2}Ni_5$
Kelly 2015	[16]	1	25; 130	140; 410	(MmCa)Ni4.95Al0.05
Sekhar 2015	[29]	2	25; 140	2; 44	S1: $LaNi_5$ S2: $La_{0.35}Ce_{0.45}Ca_{0.2}Ni_{4.95}Al_{0.05}$
HYMEC 10	[7]	2	25; 150	10; 200	S1: AB_5 ($La_{1\text{-}x}Ce_xNi_5$) S2: AB_2 (Ti, Zr – based) (no detailed information available)
SAIAMC/UWC[a]	[7]	3	25; 140	3; 200	S1: $LaNi_{4.9}Sn_{0.1}$ S2: $La_{0.8}Ce_{0.2}Ni_5$ S3: $90_{wt.}$% C14–$Ti_{0.65}Zr_{0.35}$(MnCrFeNi) + $10_{wt.}$% $La_{0.8}Ce_{0.2}Ni_5$
Ergenics 2	[30]	1	40; 175	83; 550	Not published
Ergenics 3	[31]	1	80; 400	6.9; 345	Not published
Vanhanen 1999	[12]	3	20; 80	20; 200	S1: Hydroalloy C2 S2: Hydroalloy C0 S3: TiCrMn0.55Fe0.3V0.15 (Stage 3 was not actually built in the experimental set up)

[a] SAIAMC is the South African Institute of Advanced Materials Chemistry. UWC is the University of Western Cape in South Africa.

was built for ESKOM in South Africa [7]. Both deliver hydrogen at 200 bar with a multi-stage MHC with upper temperature of 130–150 C. They also both use an AB_5-type material to compress up to 50 bar and for the next compression step an AB_2-type material is used. However SIAMC/UWC also added 10 wt% of AB_5 Material ($La_{0.8}Ce_{0.2}Ni_5$) to the high pressure stage. Even though these are very interesting results, the temperature level of the heating medium is significantly higher than the temperature that HYSTORE aims for.

Regarding the activities by Ergenics ([30–34]), an additional interesting aspect is that they also investigated the possibility of carrying out purification of a hydrogen stream from a reforming unit while compressing it. They report successful demonstration of this technology. However, no indication of commercial success of this technology could be found and all publications that relate to this topic are from the early 2000s.

There are some other relevant research activities, which do not directly deal with metal hydride compressor systems, but can still contribute to this topic. For instance, Weckerle et al. [35] published their results for a novel reactor design for metal hydride cooling very recently. They state that they could improve several aspects, such as good heat transfer into the

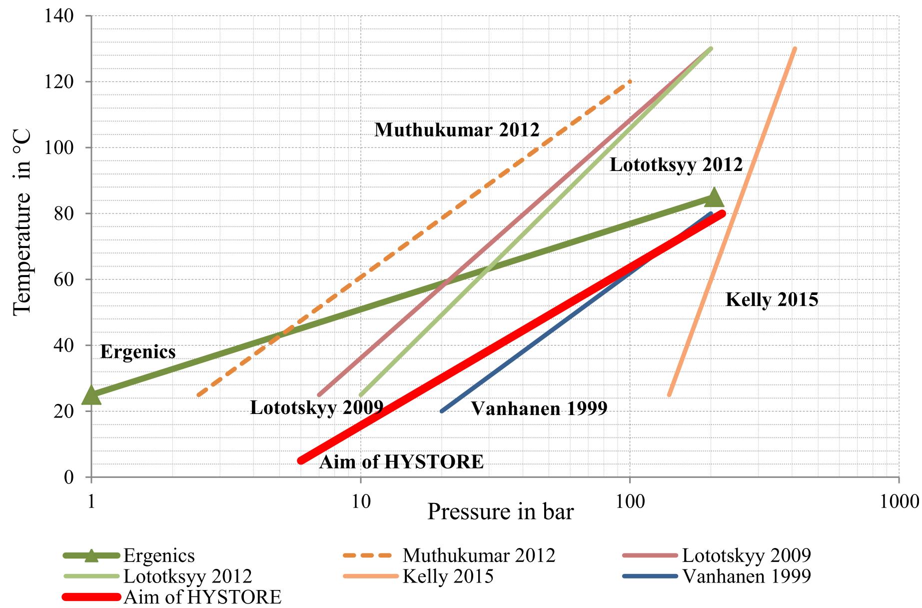

Fig. 2 – Selection of projects from Table 1, with delivery pressure ≥100 bar or higher and temperature ≤130 °C.

bed and low parasitic thermal mass of the reactor, compared to the state of the art, resulting in a high material specific cooling power. This can most likely be applied to compression with metal hydrides as well.

Development and set up of 6-stage MHC

HYSTORE technologies set up and tested a 6-stage MHC for compression of hydrogen from 7 bar, at which it is supplied, to a pressure more than 220 bar. The heating medium is water and it is planned to have a temperature of about 80 C in order to simulate a solar thermal collector. The cooling takes place around 10 °C. In a commercial application the cooling could be supplied by solar adsorption coolers. The heating and cooling medium that is used is water. The HYSTORE MHC consists of 6 metal hydride tanks that consecutively compress the hydrogen. The tanks in which the metal hydride material is stored are identical for each stage. The hydride forming material is different for each stage. The

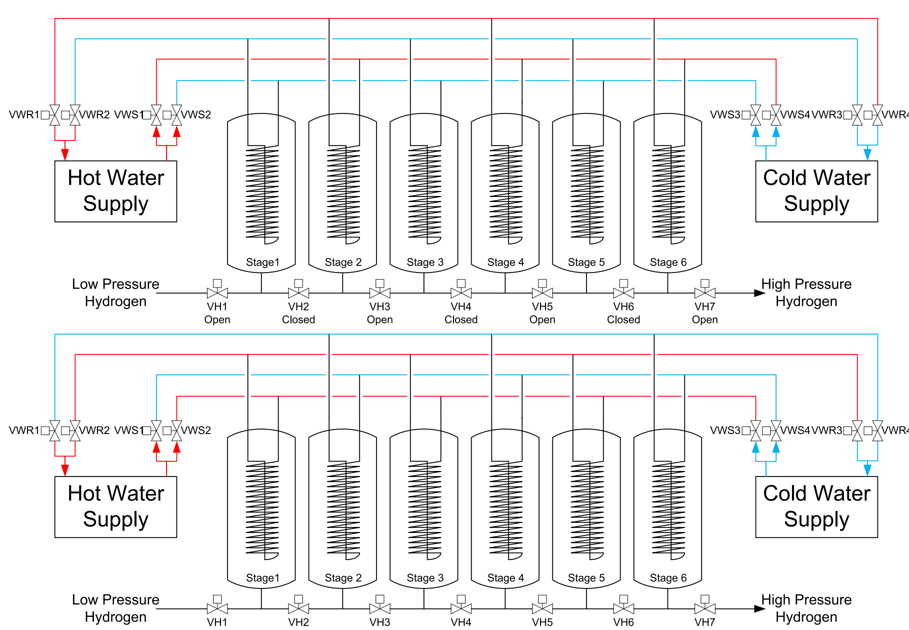

Fig. 3 – Flow sheet of HYSTORE's metal hydride compressor for the two main phases of operation. Top: Phase 1, Bottom: Phase 2.

Fig. 4 – Back part of the inner tube of the MHC tank with coiled copper cube inlet and outlet.

Fig. 5 – Coiled copper tube.

construction of metal hydride tanks, as well as the selection of metal forming alloy was carried out by HYSTORE and is presented in the following sections. In Fig. 3, a flow sheet of the MHC built by HYSTORE is shown. The flow sheet is shown in two different phases of operation. The top one shows the phase where the stages 1, 3 and 5 are cooled while the stages 2, 4 and 6 are heated (phase 1). In this phase, the Valves VWR1, VWS1, VWS3 and VWR3 are open on the water side, while the others are closed. On the hydrogen side, it is shown in the figure which valves are open and closed. Those stages that are cooled absorb hydrogen in this phase, those that are heated desorb hydrogen. In the lower flow sheet, phase 2 of the operation is shown. In this Phase VWR2, VWS2, VWS4 and VWR4 are open on the water side and stages 1, 3 and 5 are heated while stages 2, 4 and 6 are cooled. It can be seen that the overall system only takes up and releases hydrogen in Phase 1, not in Phase 2. As already mentioned, this is the case for any MHC with only one compression line. In order to achieve continuous supply of high pressure hydrogen, two or more of these set ups have to be operated in parallel and with a phase shift. It should be noted that Fig. 3 is only supposed to illustrate the interconnection between the different containers and valve set up, but not the actual geometry of the metal hydride tanks. The hydride tanks are presented in more detail in the section below.

Fig. 6 – Front part of inner tube with opening for hydrogen inlet/outlet.

Metal hydride tanks

In essence, the metal hydride tanks of HYSTORE's MHC consist of a jacketed tube, where the metal hydride is located in the inner tube and the heating/cooling water runs through the annulus between the inner and outer tube. In addition to

Fig. 7 – Completed MHC container with outer tube welded to inner tube and connection for water inlet.

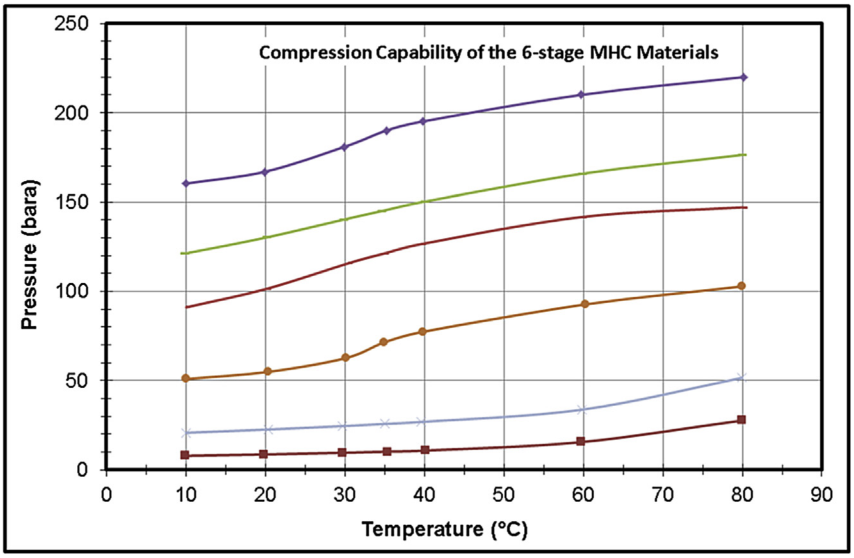

Fig. 8 – Pressure variation as function of temperature change in constant low volume container (about 3 ml) for the selected materials for the MHC.

that, to improve the heat transport inside the packed bed of metal hydride, a copper tube coil, through which the water flows, is immersed in the packed bed. The front and rear parts of the jacketed tube are closed. On the front part a single connection is located for the hydrogen to enter and exit the inner tube. On the rear part, connections to and from the copper tube coil are implemented. The outer tube has connections radially located towards the front and the back for the water to enter and exit. One of those can be seen in Fig. 7.

In Fig. 4, the back part of the inner tube with the inlet and outlet of the copper tube coil can be seen. The gap between the copper tube and the metal hydride container is later closed with fitting, which can be seen in Fig. 10. In Fig. 5, the copper tube coil is shown. In Fig. 6, the front part of the inner tube is shown with the opening for hydrogen inlet and outlet. In Fig. 7 the readily assembled container can be seen, with the outer tube welded to the inner tube, furthermore the connector for the water that runs through the annulus can be seen.

Hydride forming alloys

In a large number of PCT measurements, the characteristics of a variety of materials were determined In Fig. 8, the variation of the pressure of the selected materials with a temperature change is shown. For the production of the presented data, a constant volume (container of about 3 ml) was filled with the respective material (about 1 g) and hydrogen was supplied at the lower pressure shown and kept at a temperature of 10 °C until equilibrium was established. Subsequently, the container was closed and the temperature of the container was increased to 80 °C and the built-up of pressure was recorded. In the figure, it can be well observed how the equilibrium pressure at 80 °C of a material is higher than the equilibrium pressure of the subsequent material at 10 °C. The materials were prepared and characterized HYSTORE Technologies Ltd. For stage one an AB_5 type (La–Ce–Ni) material was selected for all other stages AB_2 type materials (Zr–Ti–Mn–Co–Cr–Fe–V) were selected. The material was crushed to a maximum particle size of 6 mm in a jaw crusher and subsequently further crushed to a maximum particle size of 1 mm in a roller crusher. The six selected alloys exhibit an

Fig. 9 – Metal hydride tanks mounted to the rack with some piping already attached.

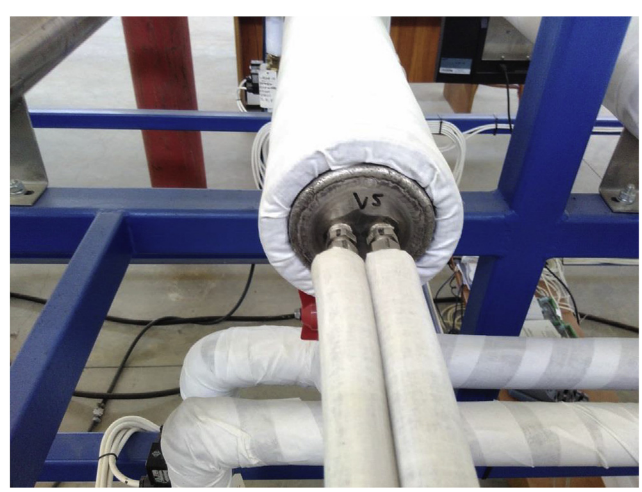

Fig. 10 – Back side of metal hydride tube readily assembled with insulation.

Fig. 11 – HYSTORE"s MHC, front view onto hydrogen piping (left), rear view onto water piping (right).

absorption pressure plateau of 7, 20, 50, 90, 120 and 160 bar respectively at 10 °C.

In each of the MHC stages 6.2 kg of material was used.

Compressor construction and set up

The 6 metal hydride containers where mounted onto a rack to fix them in a safe position and to be connected via piping. The water flow is controlled via solenoid valves, its pressure can be checked on bourdon type pressure indicators. For hydrogen pressure monitoring, both bourdon type indicators as well as electronic pressure transmitters were installed. In Fig. 9, the metal hydride tanks are shown. Furthermore, the pressure indicators and sensors for the hydrogen pressure between the stages as well as parts of the piping can be seen. In Fig. 10, the back side of one of the metal hydride containers in the readily assembled metal hydride compressor can be seen. As can be seen in the Figure insulation was installed to the water piping as well as the metal hydride container itself to reduce heat losses.

Out of safety considerations a 220 bar pressure relieve valve is attached to the piping at the final stage of the MHC compressor. The pressure relieve valve can be seen on the right hand side of Fig. 9. The water supply pipes are connected to a conventional unit for domestic hot water supply for the hot water supply and a water cooling unit for cold water supply.

In Fig. 11 the complete and readily assembled MHC can be seen. On the left hand side of the figure the front view with the hydrogen piping and connections can be seen. On the right hand side of the figure, the back side with the piping to the coiled water tube can be seen.

Operational results

The results of operation of the prototype MHC compressor are summarized in Fig. 12 and Fig. 13. The periodic operational mode of the compressor can be well recognized in the plot. Furthermore, it can be seen that the operation is stable and compression cycles are consisted, with exception of the first cycle during which a stable operation had still to be found. It can be very well seen in the figure, that the desorption pressure of one stage is the absorption pressure of the subsequent stage, as the two lines appear as one.

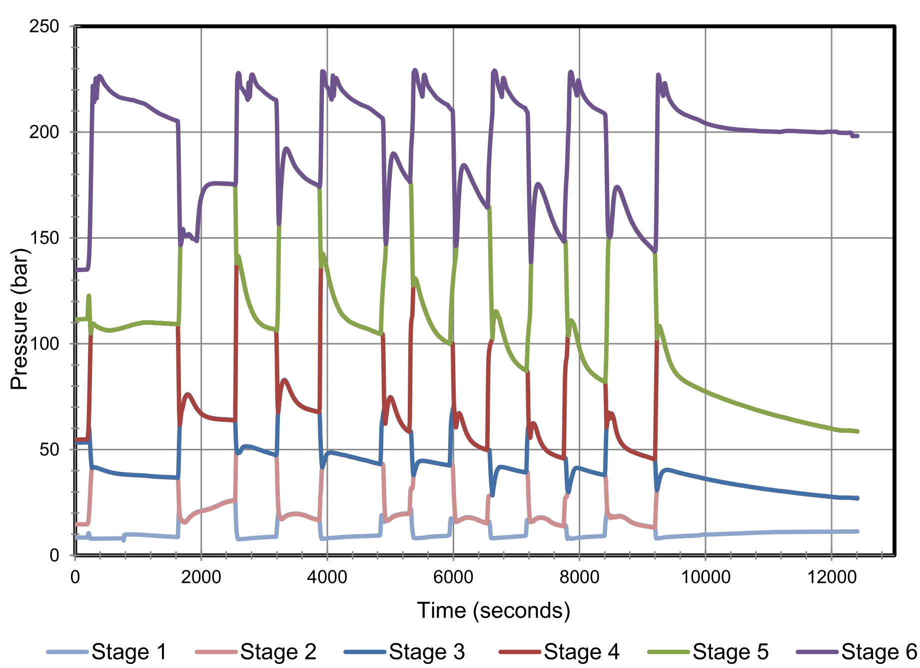

Fig. 12 – Pressure in the 6 MHC stages over time.

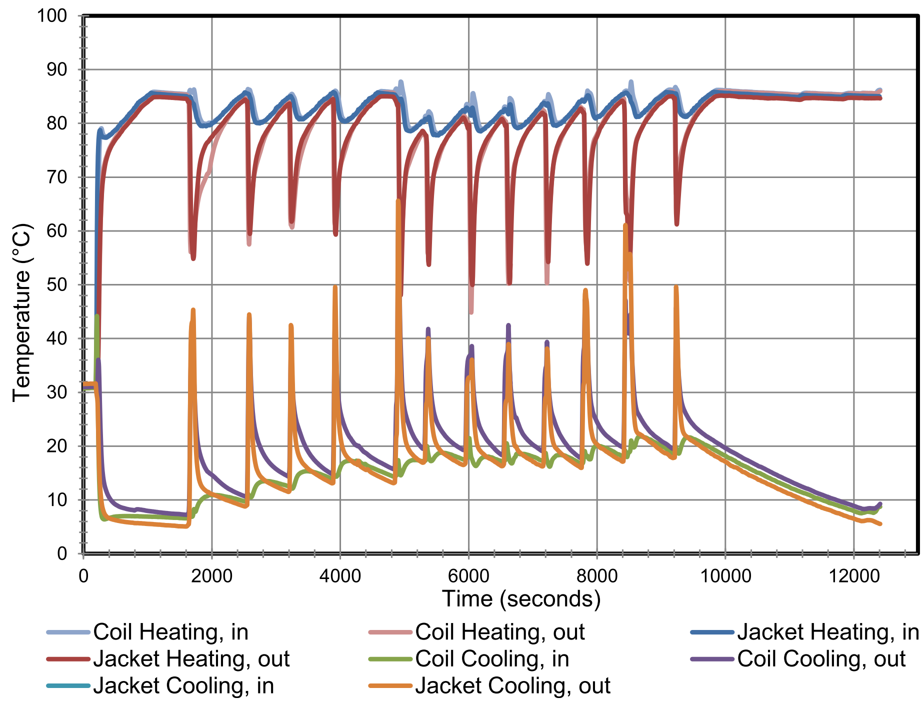

Fig. 13 – Temperature of cooling and heating water at inlet and outlet.

Furthermore, the overall compression from 7 bar to 220 bar can be observed.

In Fig. 13, the temperature of the inlet and outlet of the cooling and heating water over the same time period is shown. It can be seen that the heating temperature is constant throughout operation, while the cooling temperature increases to a value of 17 °C throughout operation. However as the full compression ratio can be achieved throughout time (shown in Fig. 12), it can be concluded that the increase in cooling temperature up to 17 C has no negative effect on the performance. In the outlet temperature of the heating water a downward spike can be seen for each cycle (both coil and jacket). The same can be observed for the cooling water with an upward spike. This is caused by the sensible cooling that has to be done to cool/heat the material from absorption to desorption temperature and vice versa.

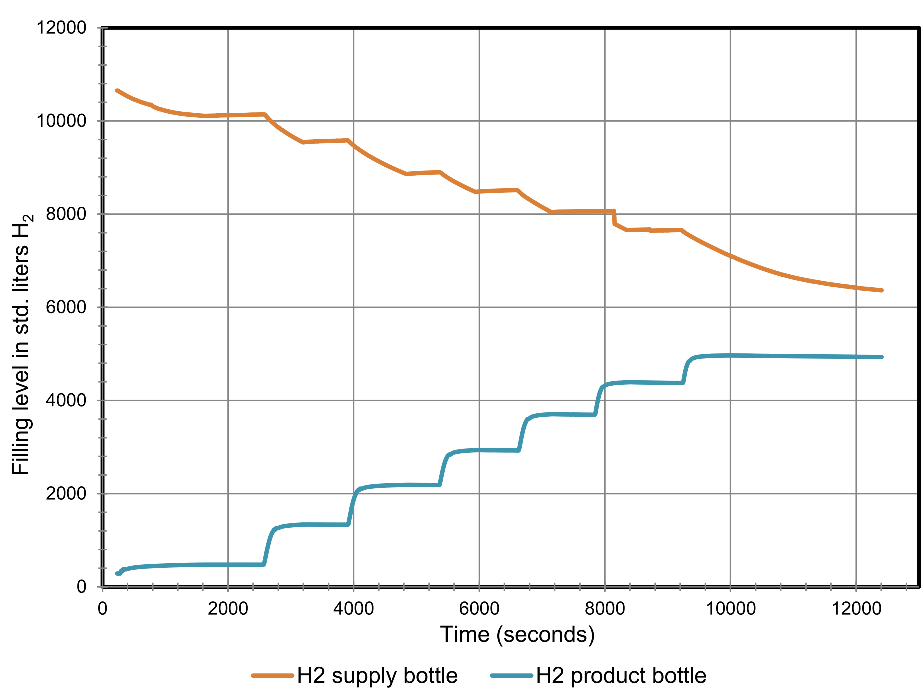

Fig. 14 – Change in hydrogen amount in supply and product container over time.

In Fig. 14, the change in hydrogen amount in the supply bottle (low pressure, orange line) and hydrogen amount in product bottle (high pressure, blue line) over time is presented. Again the periodic operational mode can be well observed from this graph. It can also be seen that approximately 3900 std. liters of hydrogen are pumped between seconds 2565 and 9185 ($\Delta t = 6620$ s) in 5 cycles. Hence the average pumping capacity is approx. 2121 std. liters of hydrogen per hour. With a total material mass of 37.2 kg, this corresponds to a specific pumping capacity of 59.5 L of hydrogen per kg and hour. However, pumping capacities up to 2500 std. liters of hydrogen per hours 67.2 l_{H2} kg^{-1} h^{-1} could be observed throughout testing. It is assumed, that the value of 2500 std. liters per hour can be continually achieved after more experience is gathered in the operation of the MHC.

Summary & conclusions

A significant amount of R&D activities in the field of metal hydride systems exists, both regarding material development as well as systems design for metal hydride hydrogen compression. However, regarding material development, most work focusses on metal hydride for hydrogen storage application. Those that focus on metal hydride hydrogen compression usually consider higher desorption temperatures than the ones aimed for by HYSTORE, namely 10–80 C which are suitable to be operated with solar heat and solar cooling.

The MHC constructed and operated by HYSTORE has shown stable operation and achieved compression of hydrogen from 7 to 220 bar with moderate heating at about 80 °C which could be supplied by solar collectors. Furthermore the cooling was initially carried out at 5 °C but an increase to 17 °C has shown no negative effects on the compression performance. Therefore, it can be expected that a solar adsorption cooler can easily achieve the required cooling capacity. Hence, the original aim of HYSTORE was achieved. The specific productivity of the metal hydride compressor achieved up to 67.2 l_{H2} kg^{-1} h^{-1}.

In the future, the long term stability of the compressor operation has to be assessed. Furthermore, it is planned to construct another MHC with more stages in order to achieve an outlet pressure of >350 bar with the same heating and cooling temperatures. Furthermore, additional attention will be paid to energy (heating/cooling) consumption and its reduction in order to determine and improve the efficiency. Finally, when this is done, a system's study will be carried out to assess the lifecycle cost of such a compression unit and its potential benefit compared to conventional hydrogen compressors.

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