Analysis of the Storage Capacity of An Uncooled MH Tank

Romana Dobáková[1*]; Lukáš Tóth[2]; Natália Jasminská[3]; Peter Milenovský[4]

Department of Energy Engineering, Faculty of Mechanical Engineering, Technical University of Košice, Slovakia
*Corresponding Author

Received: 01 September 2025/ Revised: 08 September 2025/ Accepted: 13 September 2025/ Published: 30-09-2025

Abstract— *The need for cooling of metal hydride (MH) tanks during the hydrogen absorption process is a well-known fact, especially when it is necessary to achieve full absorption of the alloy with hydrogen within a short time frame. However, effective cooling of the tank is not always possible. The absence of cooling significantly extends the absorption time or reduces the absorption capacity of the alloy, which is crucial for the competitive operation of a metal hydride tank. This article focuses on the effect of the absence of an external cooling system on the change in the absorption capacity of the MH alloy within a defined filling time frame.*

Keywords— Metal Hydride, Hydrogen, Absorption, MH alloy.

I. INTRODUCTION

Hydrogen is considered one of the most promising energy carriers, as it is renewable and has the potential to significantly contribute to decarbonization and the reduction of greenhouse gas emissions not only in transportation but also in the energy sector and industry. However, efficient and safe storage of hydrogen presents a major challenge for the further development of hydrogen energy.

One of the main obstacles in hydrogen storage, whether for short-term or long-term use, is its very low energy density, small molecular size, and wide explosive concentration range when mixed with air. These negative factors significantly complicate its safe storage and distribution within the hydrogen infrastructure. This is evident not only in its use at refuelling stations for hydrogen-powered vehicles but also in heating systems, where previously unforeseen complications can arise.

Solving the issue of effective and safe hydrogen storage is a key prerequisite for its broad application in both industrial and mobile uses. If hydrogen is to become a competitive energy carrier in the near future, its storage method must meet multiple criteria particularly low cost, long service life, ease of installation, and other technical, safety, and economic requirements.

The most common hydrogen storage solutions include systems based on compression, absorption, adsorption, and liquid carriers, whether it be liquefied hydrogen or liquid organic hydrogen carriers (LOHC). Each of these methods has its own advantages and disadvantages in terms of mass and volumetric density, cost, filling and release speed, as well as durability and safety.

Therefore, the selection of a suitable storage method always depends on the specific application whether it is mobile or stationary, short-term or long-term.

II. METAL HYDRIDE ALLOYS

Storing hydrogen in metal hydride alloys represents one of the innovations in the development of alternative technologies for both short-term and long-term hydrogen storage. In this method, hydrogen chemically bonds with metals or metal alloys, forming so-called metal hydrides. These materials are capable of reversibly absorbing and releasing molecular hydrogen under specific pressure and temperature conditions, allowing for repeated cycles without significant degradation of the material.

When in contact, gaseous molecular hydrogen reacts with the metal alloy, dissociates into atomic hydrogen, and subsequently diffuses into the intermetallic structure of the alloy, forming a metal hydride (MH) according to the general reaction:

$$\mathrm{M} + \frac{\mathrm{x}}{2}\mathrm{H_2} \leftrightarrow \mathrm{MH_2} + \mathrm{Q} \tag{1}$$

Where M is a metallic solid solution or intermetallic compound, H – hydrogen, x – molar fraction of hydrogen (1), MH – corresponding metal hydride, Q – reaction heat ($\mathrm{J \cdot mol^{-1}}$).

The process of hydrogen absorption into metal hydride alloys is accompanied by an exothermic reaction, during which a significant amount of thermal energy is released. Due to the thermal load, it is essential to ensure an effective cooling system for the MH tank, as increased temperature negatively affects the absorption kinetics, leading to a slower absorption process.

The absorption and desorption processes occur at relatively low pressures and temperatures, making this method suitable for both industrial and mobile applications, as it does not require powerful compressors, pressure boosters, or cryogenic cooling systems.

MH tanks allow compact storage of hydrogen in the solid phase with high volumetric density, which significantly increases the overall safety of the system. Since most of the hydrogen in the tank is bound within the structure of the metallic material, the risk of hydrogen diffusion through connecting elements is minimized due to the lower pressure exerted by hydrogen on these joints.

The main disadvantages of metal hydride hydrogen storage include low gravimetric capacity, as most commonly used alloys can store only 1–2 wt.% of hydrogen, which is a significant limitation, especially for mobile applications. Another drawback is the higher weight of the entire system, which negatively affects its usability in transportation vehicles.

An additional challenge is thermal management, since the exothermic absorption of hydrogen requires effective cooling, while desorption demands heat input. Moreover, the cost and availability of certain key elements such as lanthanum, vanadium, or titanium significantly increase the production costs of these materials.

III. STORAGE CAPACITY OF AN UNCOOLED MH TANK AS A FUNCTION OF ABSORPTION PRESSURE

For the purpose of the experiment on the storage capacity of a MH alloy as a function of temperature, the Hydralloy C5 alloy was used. It is a metallic alloy with the chemical composition $\mathrm{Ti_{0,95}Zr_{0,05}Mn_{1,46}V_{0,45}Fe_{0,09}}$. These materials are capable of absorbing hydrogen from the gas phase at low temperatures and pressures, forming reversible metal hydrides, which makes them suitable for hydrogen storage.

During the absorption process, the metal hydride alloy releases heat, which must be effectively removed from the system to maintain the desired kinetics of the entire process.

The amount of heat Q_{stored}, released during full saturation of the metal hydride alloy with hydrogen can be calculated using the following equation:

$$Q_{\mathrm{stored}} = \frac{m_{\mathrm{MH}} \cdot \alpha_{\mathrm{MH}}}{\rho_{\mathrm{H2}} \cdot 100} \cdot Q_{\mathrm{MH}} \tag{2}$$

where m_{MH} weight of MH alloy in tank (kg), α_{MH} – gravimetric storage percentage (%), ρ_{H2} – density of hydrogen under standard conditions ($\mathrm{kg \cdot m^{-3}}$), Q_{MH} – amount of heat released during absorption of 1 $\mathrm{m^3}$ of hydrogen (J).

The thermal power that must subsequently be removed from the tank is determined by the following relation:

$$P_{\mathrm{stored}} = \frac{Q_{\mathrm{stored}}}{\tau} \tag{3}$$

where τ is time of filling of the tank (s).

The storage capacity of the MH alloy is also influenced by the absorption pressure. As can be seen in Fig. 1, the alloy exhibits the highest storage capacity at a pressure of 67 bar (6.7 MPa). It is also evident that beyond a certain pressure value, further increases in pressure do not lead to a significant increase in the alloy's capacity. This is because the alloy's structure is unable to absorb additional amounts of hydrogen despite the increasing pressure. The subsequent increase in the volume of stored hydrogen in the MH tank then proceeds similarly to that in standard high-pressure tanks.

For the purpose of experimentally determining the gravimetric storage capacity of the uncooled MH alloy, a shortened MNTZV-60 type tank equipped with an integrated internal thermometer was used. This is a low-pressure metal hydride hydrogen tank suitable for both mobile and stationary applications (Fig. 2). The tank was connected to a compressed hydrogen supply line, where a flow meter with a maximum flow capacity of 20 $l \cdot min^{-1}$ and a pressure gauge with a range up to 40 bar (4 MPa) were installed on the inlet pipe.

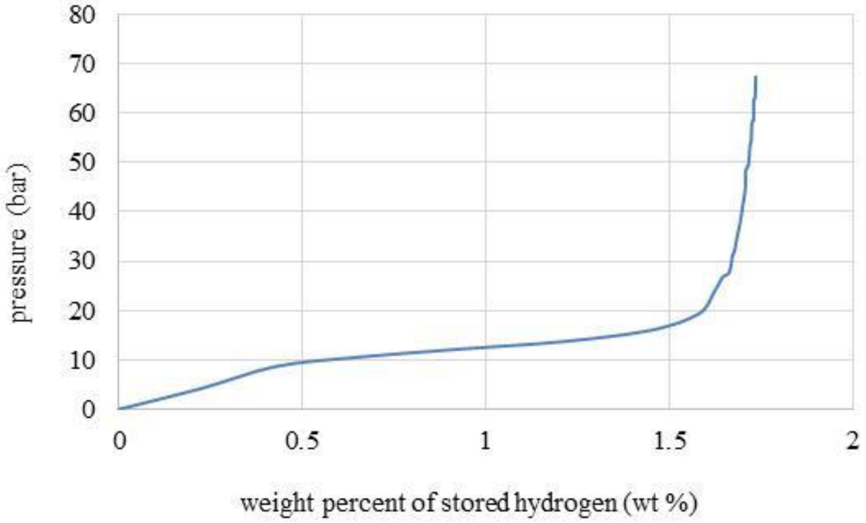

FIGURE 1: Change in storage capacity with increasing pressure at 20 °C (ideal storage capacity)

Before the measurement, the tank was activated in accordance with the manufacturer's methodology. Subsequently, a four-hour vacuuming of the system was performed to a relative pressure of -1 bar to ensure optimal conditions for hydrogen absorption. After vacuuming, the maximum hydrogen flow at the desired pressure was set to 20 $l \cdot min^{-1}$ using a needle valve and bypass. Once the flow stabilized, the bypass was closed and the tank valve was opened, allowing hydrogen to flow directly into the tank. The experiment was conducted at room temperature of 23 °C. The total filling time was set to 30 minutes, which can be considered a technologically acceptable filling time for this type of tank.

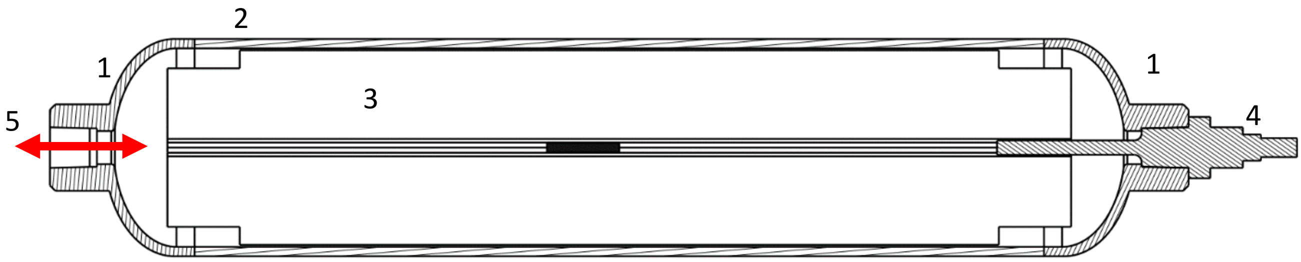

FIGURE 2: MNTZV-60 type tank equipped with an integrated internal thermometer

1 – tank cover, 2 – cylindrical part of tank, 3 – aluminium heat transfer intensifier, 4 – thermometer, 5 – inlet and outlet of hydrogen

During the experiment, the tank was filled at three different pressures: 10, 20, and 30 bar. For each of these values, the gravimetric storage capacity of the tested MH alloy (w_{MH}) under real (uncooled) conditions was determined as the ratio between the mass of absorbed hydrogen and the mass of the alloy:

$$w_{MH} = \frac{m_{H_2}}{m_{MH}} \cdot 100 \qquad (wt.\%) \tag{4}$$

where m_{H2} is weight of stored hydrogen (kg), m_{MH} – weight of MH alloy (1.567 kg).

The mass of stored hydrogen is determined by the relation:

$$m_{\mathrm{H2}} = \rho_{\mathrm{H2}} \cdot V_{\mathrm{stored\,H2}} \ \text{(kg)} \tag{5}$$

where V_{storedH2} is the volume of hydrogen stored in the metal hydride alloy (m^3), ρ_{H2} – hydrogen density ($kg \cdot m^{-3}$).

Table 1 shows the gravimetric storage capacities of the MH alloy at the three tested pressures. As can be seen from the table, the storage capacity of the MH alloy increases with increasing pressure, which is caused by the improved absorption properties of the material at higher hydrogen pressures. The increase in storage capacity of the uncooled MH alloy with rising pressure follows the same trend as in the case of the cooled MH alloy.

TABLE 1
STORAGE CAPACITY OF THE MH ALLOY AT THE INVESTIGATED PRESSURES

Pressure (bar)	$t_{\mathrm{MH,max}}$ **(°C)**	$V_{\mathrm{storedlH2}}$ **(m^3)**	ρ_{H2} **($kg \cdot m^{-3}$)**	m_{H2} **(kg)**	w_{H2} **(wt.%)**
10	40	0.0396	0.08988	0.003559	0.2271
20	50	0.0633	0.08988	0.005689	0.3631
30	60	0.0956	0.08988	0.008593	0.5483

In comparison with the storage capacity at 20 °C (see Fig. 1), it can be observed that the storage capacity decreases as the temperature inside the tank increases. This reduction in storage capacity is a consequence of the exothermic nature of the reaction between hydrogen and the alloy. As the alloy's temperature rises, the reaction slows down, leading to a decrease in the amount of hydrogen that can be stored within a given time.

Figure 3 illustrates the dependence of the alloy's temperature change during hydrogen absorption at three different pressures as a function of the filling time of the MH alloy.

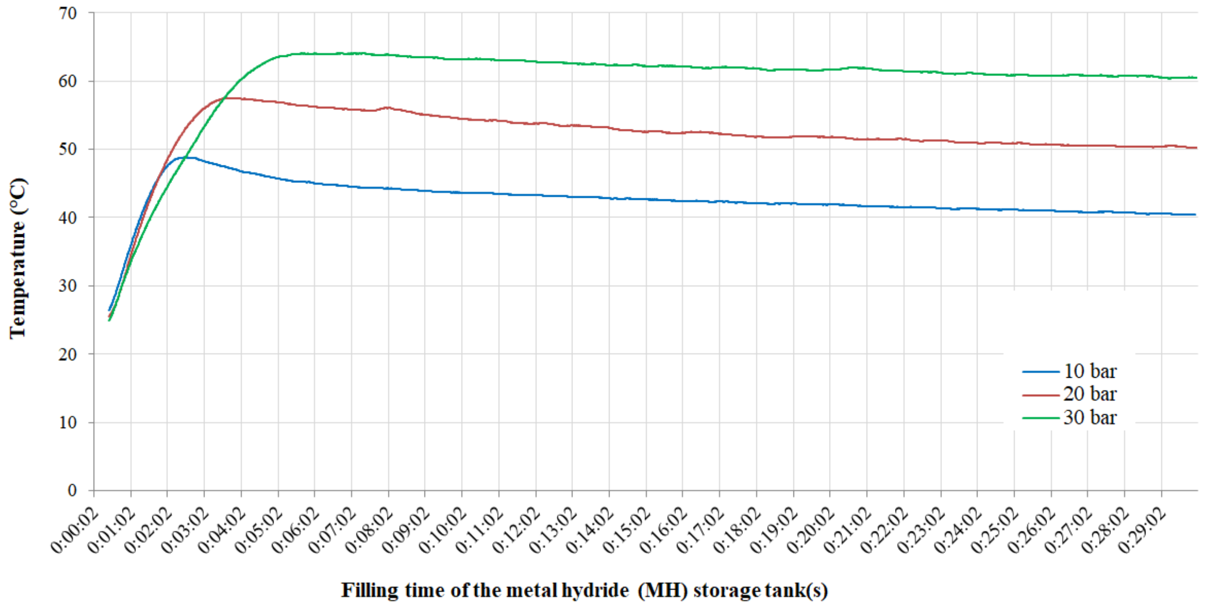

FIGURE 3: Change in alloy temperature during hydrogen absorption at three different pressures as a function of MH alloy filling time

The graph shows that higher hydrogen pressure allows the absorption process to proceed even at an increased temperature of the MH alloy. As a result, the fast absorption phase can last longer, leading to the binding of a greater amount of hydrogen before the alloy reaches a temperature at which the absorption kinetics significantly slow down.

Figure 4 presents a comparison of the hydrogen flow into the MH alloy and the total amount of hydrogen stored in the MH alloy as a function of filling time at three different hydrogen pressure levels.

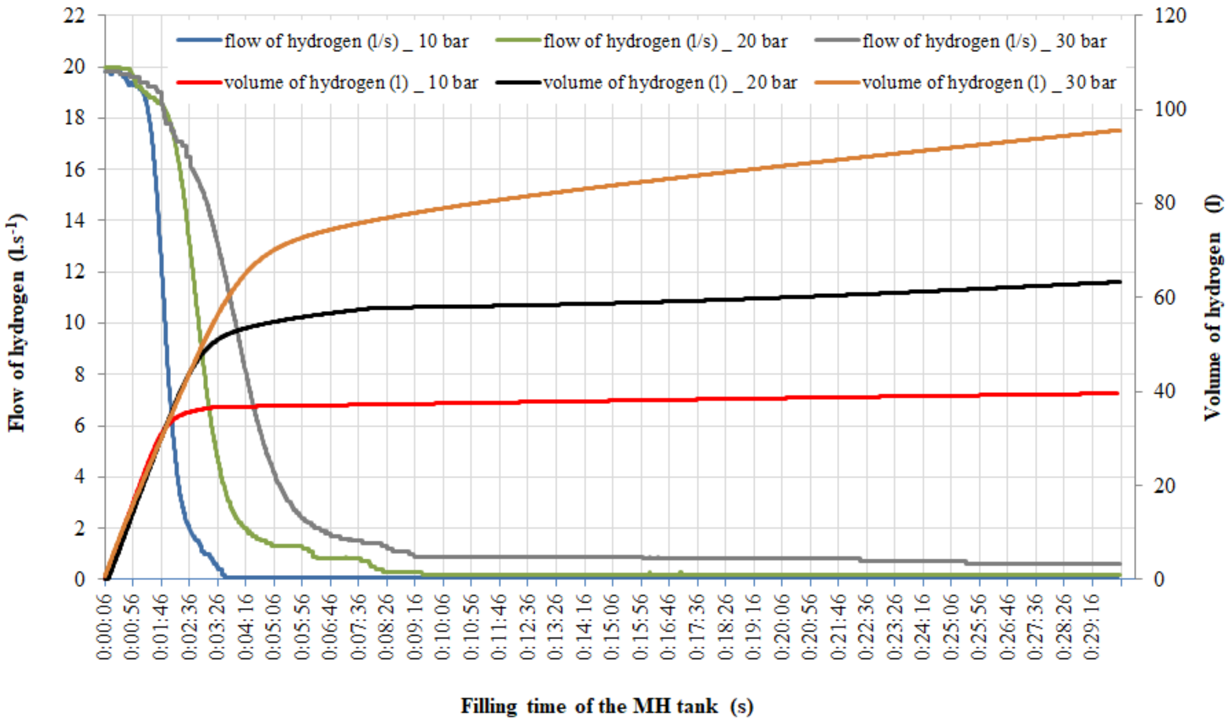

FIGURE 4: Hydrogen flow into the MH alloy and the total amount of hydrogen stored in the MH alloy as a function of filling time at three different hydrogen pressure levels

The hydrogen flow into the MH alloy exhibits a nonlinear behaviour. Higher hydrogen pressure prolongs the phase of intensive hydrogen absorption into the alloy before the onset of its slowdown, enabling more efficient use of the alloy's absorption capacity within a shorter time. As the pressure increases, the total amount of hydrogen that can be absorbed into the alloy during the same time interval also rises. Although higher pressure accelerates the initial absorption process, it simultaneously causes more intense heat release, leading to overheating of the MH alloy and subsequent slowing down of the absorption reaction kinetics.

IV. CONCLUSION

Even when using internal elements to improve heat transfer (intensifiers), an external cooling system remains essential to maintain optimal hydrogen absorption conditions in MH tanks if the filling process is time-limited. Otherwise, heat accumulates, leading to an increase in alloy temperature and a consequent decrease in absorption capacity.

Experimental results show that at a pressure of 10 bar, the stored hydrogen capacity at 40 °C is approximately 65.06% lower than at 20 °C; at 20 bar, it is 77.31% lower; and at 30 bar, the difference between the ideal storage capacity and the capacity of the uncooled MH tank with limited filling time is 66.77%.

By extending the tank filling time at a given pressure, the actual storage capacity would gradually approach the ideal capacity, and after a sufficiently long period, the difference between ideal and real filling times would completely disappear.

The development of systems for adequate cooling of MH tanks during the absorption process is crucial for their wider adoption, along with research into heat dissipation systems from the tank core, as the thermal conductivity of powdered alloys significantly complicates this process.

Alongside cooling research, the development of new alloys with improved properties such as higher capacity, faster kinetics, and better thermal conductivity must also proceed. This progress could significantly expand the usability of metal hydrides and contribute to the broader spread of the hydrogen economy.

ACKNOWLEDGEMENTS

This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-21-0274 and APVV-23-0266.“ Further supported by VEGA granting agency within the Project No. 1/0224/23, Project No. 1/0587/25; by KEGA granting agency within the Project No. 031TUKE-4/2025.

REFERENCES

[1] Kölbig, M., Bürger, I., Linder, M.: *Thermal applications in vehicles using Hydralloy C5 in single and coupled metal hydride systems*. In: Applied Energy. 287, 2021, 116534.

[2] Capurso, G. and et al.: *Development of a modular room-temperature hydride storage system for vehicular applications*. In: Applied Physics. 122, 2016, 236.

[3] Giorgio, D.P and et al.: *Innovative battery thermal management system based on hydrogen storage in metal hydrides for fuel cell hybrid electric vehicles*. In: Applied Energy. 315, 2022, 118935.

[4] Jasminská, N., Brestovič, T., Lázár, M.: *Výroba a uskladnenie vodíka*. Košice: TU, 2015. 141 p. ISBN 978-80-553-2378-7.

[5] Martin, M., Gommel, C., Borkhart, C., Fromm,E.: *Absorption and desorption kinetic of hydrogen storage alloys*. In: JournalofAlloyss and Compounds. 238 (1-2), 1996, 193-201.

[6] Rudman, P.S.: *Hydriding and dehydridingkinetics*. In: J. Less-Common Met. 89(1), 1983, 93-110