Design and calculation of heat transfer of the passive cooling modules for low-pressure hydrogen vessels

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Abstract

This paper deals with the issue of improving the temperature management of a metal hydride tank to reduce the energy intensity of cooling. The problem of absorption and adsorption of hydrogen gas in metals, cooling of metal hydride tanks in the process of hydrogen absorption while protecting the current level of development of science and research for this area is analysed. The work also deals with numerical and experimental verification of a prototype metal hydride tank with passive cooling.

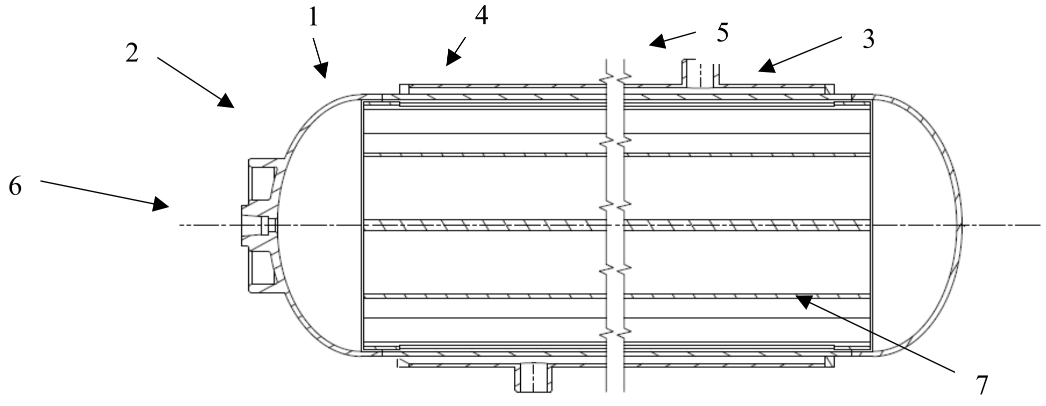
Keywords: Metalhydride, pressure vessel, stress analysis, hydrogen

Introduction

Sustainable energy determines all aspects of the functioning of modern society. A fully integrated and well-functioning internal energy market is an essential part of a sustainable national economy, of which the gradual transformation into a system characterized by a significant degree of carbon neutrality is currently highly topical. Achieving a balance between carbon emissions and their absorption by natural systems require a significant shift away from fossil fuels, a rapid increase in the share of renewable energy in total consumption, the constant development of green technologies to increase their efficiency and the use of climate-neutral energy carriers such as hydrogen. For hydrogen to become a real alternative to fossil fuels in the long term, it is necessary to look not only for environmentally friendly non-fossil resources, but also for efficient systems enabling its long term and safe storage. One of the methods of hydrogen storage is the use of low-pressure technology, which works on the principle of absorption and desorption of hydrogen from metal hydrides. If metal hydrides are used for hydrogen storage, it is necessary to address the temperature management, which means cooling the alloy during hydrogen absorption and heating the alloy during hydrogen adsorption.

1. Design of low-pressure vessel

The design of the vessel is based in the standard STN EN 13322-2. This standard describes transport gas vessels, the design and manufacture of refillable steel gas vessels. The structure consists of two main parts as shown on Figure 1, which are the main body of the vessel and the secondary casing system in which coolant flows. The material used for vessel is stainless steel type 1.4404. The mechanical properties of used steel age shown in Table 1.



where: 1- Cylindrical part of the main body, 2- Elliptical bottom, 3-Flange for the secondary casing system where coolant flows, 4-Cyllindrical part of the secondary casing system, 5- Flange G1/2“, 6-Flange NPT1/4“, 7- Heat transfer intensifier

Figure 1. Design of low-pressure vessel

Table 1. Mechanical properties of stainless steel 1.4306

0.2% Re (MPa)	**Rm (MPa)**	**ρ ($kg\cdot m^{-3}$)**	**μ**	**E (MPa)**
190	460-680	7950	0,3	$2{,}1\cdot10^5$

where: Re- Yield strength of selected material, Rm- Tensile strength of selected material, ρ- Density, μ- Poisson 's number, E- Young's modulus of elasticity

2. Design of passive cooling modules

Since the heat is generated in the process of hydrogen absorption in metal hydride, which takes place a pressure 3 MPa, it is necessary to design a cooling system that will dissipate excess heat. The next design will focus on the design of various modules allowing heat dissipation from the volume of the metal hydride alloy towards its edges to homogenize the temperature field of the metal hydride alloy. One way to make the heat removal from the volume of the metal hydride alloy formed in the absorption process more efficient is to place the passive module in the powder alloy, which will have much higher thermal conductivity compared to the alloy. In our case, we are talking about an aluminium intensifier, which distributes the generated heat towards the shell of the vessel, on which is placed a passive cooler formed by circumferential fins. In the second case heat dissipation is ensured in the form of active cooling, by applying a heat transfer medium, which in this case is water. Figure 2 shows a model of the proposed heat transfer intensifier.

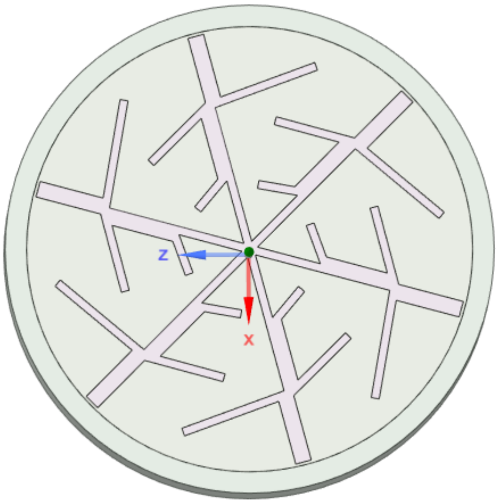


Figure 2. Designed heat transfer intensifier

Designed heat transfer intensifier was later used in simulations in program called ANSYS CFX.

3. Simulation of heat transfer using proposed intensifier in the vessel

In this chapter, a numerical simulation of the passive cooling of the vessel in the hydrogen absorption process is performed and the influence of the intensifier on the temperature field distribution in the metal hydride alloy in the hydrogen absorption process using ANSYS CFX simulation tool is analysed.

Hydrogen uptake takes place in a time range of 0 to 1200 s. During this time, hydrogen is stored in the alloy, which is associated with heat generation. For the simulation, the internal heat source was set to 401 730,1 $W \cdot m^{-3}$. The bulk density of the metal hydride powder has 3000 $kg \cdot m^{-3}$ and its thermal conductivity is $1W \cdot m^{-1} \cdot K^{-1}$. A 10 mm thick body cut-out from cylindrical pressure vessel with metalhydride alloy and an intensifier was chosen for the simulation.

The intensifier consists of six main fins, where there are 3 side fins on each of main fin. By increasing the distance of the main and secondary fins in the radial direction, the homogeneity of the temperature field in the volume of hydrogen-absorbing metal hydride is improved. The inlet cooling water temperature was set at 10°C and 30°C in the second simulation.

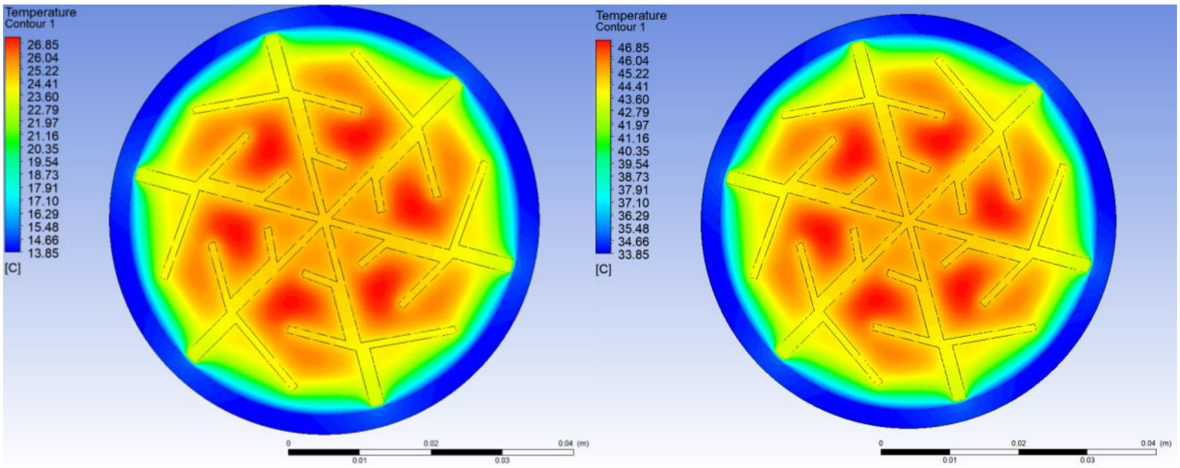


Figure 3. On the left is the temperature field at 10°C and on the right is temperature field at 30°C

In both cases of cooling the surface of the vessel with a heat transfer medium, at a temperature 10°C and 30°C, a significant stabilization of the temperature field can be seen, with the temperature in the metalhydride not exceeding more than 50°C as shown in figure 3.

The maximum temperature of the metal hydride at an equilibrium pressure of 2,5MPa is assumed to be approximately 52,5°C. After reaching mentioned temperature the alloy stops absorbing hydrogen into its structure until the temperature drops or the pressure increases. Figures 4 and 5 show the evolution of the maximum temperature in the vessel over a period of 1200 s, where it is possible to see how the temperature increases from the initial 20°C to the maximum temperature in a time of 1200 s in the presence of cooling water at 10°C and 30°C.

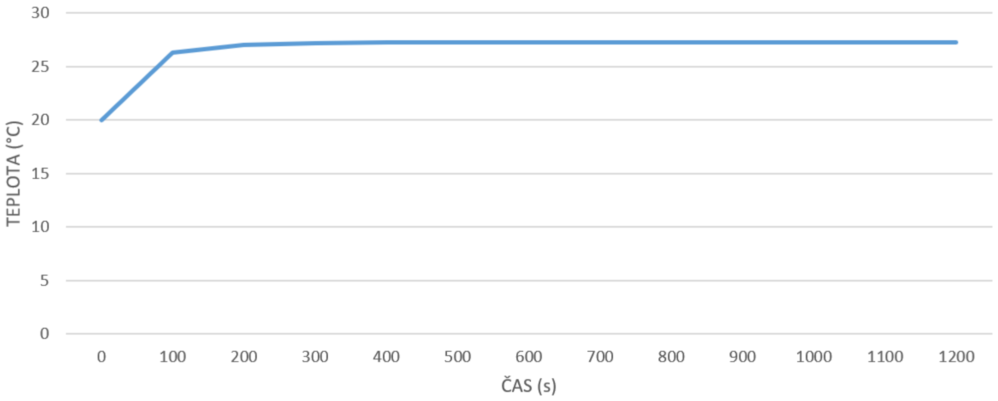
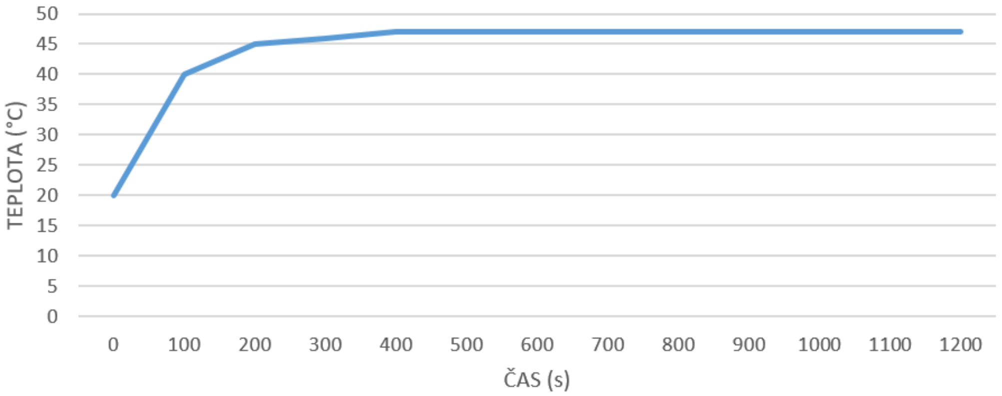


Figure 4. Display of the development of maximum temperature in the vessel as a function of time with cooling water temperature at 10°C



Obr. 5 Display of the development of maximum temperature in the vessel as a function of time with cooling water temperature at 30°C

4. Conclusion

Based on the results of numerical calculations, it can be concluded that placing a heat transfer intensifier in the volume of metal hydride significantly stabilizes the temperature field and aids in the heat transport process, thus speeding up the kinetics of hydrogen storage and shortening the time required to reach 100 percent charge. Hydrogen uptake in the metal hydride alloys can be considered as a promising alternative to low pressure hydrogen storage, which significantly increases the safety of hydrogen systems.

5. Acknowledgement

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