Design of Passive Cooling Module for Metalhydride Vessel for Hydrogen Storage

Filip Duda[1*], Tomáš Brestovič[2], Natália Jasminská[3], Ivan Mihálik[4], Šimon Hudák[5]

Technical University of Košice, Faculty of Mechanical Engineering, Department of Power Engineering, 042 00 Košice, Slovakia

*Corresponding Author

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Abstract— *The article addresses the design and calculation of heat transfer in the program ANSYS CFX of passive cooling module for metal hydride low-pressure vessels, which main purpose is to store hydrogen used in mobile applications such as automobile or bus.*

Keywords— ***Heat exchanger, heat transfer, Hydrogen, hydrogen storage, metalhydride vessel.***

I. INTRODUCTION

Hydrogen is most abundant element not just on earth but also in the universe and has very promising future as an energy carrier. The largest amount of hydrogen is of course bound in water and hydrocarbons. Hydrogen has a low bulk density, so it contains a relatively small amount of energy. To work with hydrogen several challenges must be addressed. First challenge is hydrogen production, second is distribution and third is storage. This article addresses the challenge of storage. Most abundant way of storing a hydrogen is by using high-pressure vessels, next is by using cryogenic vessels and lastly there is hydrogen storage in low-pressure vessels by absorbing hydrogen into metal alloy structure. Hydrogen storage in metal hydrides represents the possibility of storage in low pressures as well as in low temperatures. Used metalhydride in our vessel is based on elements La Ce Ni. The only disadvantage is low thermal conductivity of metallic alloys and generated heat from hydrogen storage. Since there is generated heat by hydrogen storage in low-pressure vessels, passive and active cooling modules must be present. This article solves the problem of implementing passive cooling module into low-pressure vessel.

II. HYDROGEN STORAGE IN METAL HYDRIDES

Storing hydrogen in form of solids with formation of metal hydrides (intermetallic and complex hydrides) is a very attractive technology for safe and efficient way of storage. Metal hydrides have much higher density than in comparing with liquid or gaseous storage. Hydrogen storage in metal hydrides is based on the properties of some metals, which can absorb hydrogen atoms into their metal lattice. Also, due to the relatively low operating pressures, solid state hydrogen storage is considered a relatively safe technique.

III. DESIGN OF METAL HYDRIDE VESSEL

The design of the metalhydride low-pressure vessel must be created according to standard STN EN 13322-2. Name of mentioned standard is „Transport gas cylinders, design and production of refillable steel gas cylinders “. Created vessel consist of two parts which are primary body and casing system for the flow of coolant and heating fluid as can be seen in Fig 1.

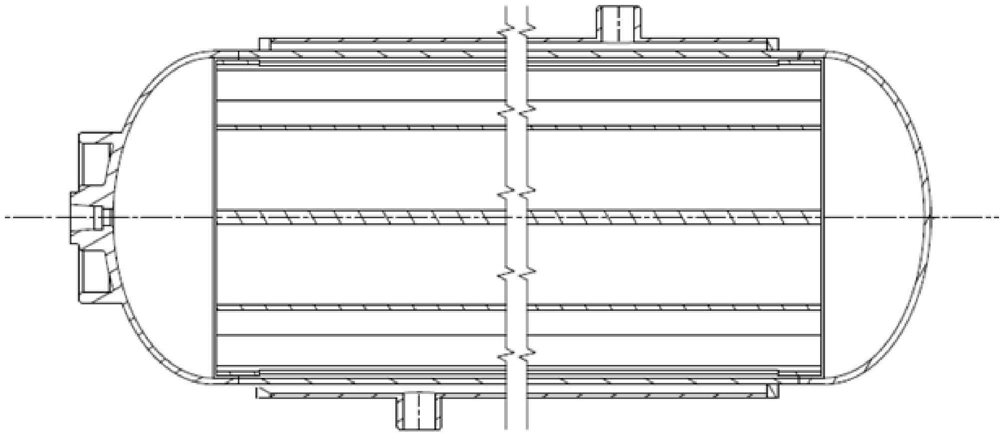

FIGURE 1: Design of low-pressure vessel

Stainless steel 1.4404 316L with parameters shown in Table 1 was chosen for the construction of the vessel.

TABLE 1
MECHANICAL PROPERTIES OF STAINLESS STEEL 1.4404 316L

0,2% Re (MPa)	Rm (MPa)	ρ ($kg\cdot m^{-3}$)	μ	E(MPa)
200	500-700	8000	0.3	$2.1\cdot10^5$

IV. CONSTRUCTION DESIGN OG PASSIVE COOLING MODULE

A heat transfer intensifier is inserted into the vessel. This intensifier is made from aluminium and serves as passive cooling module. The main role of intensifier is to increase dissipation of heat from the core of the vessel to the shell, where the vessel is cooled by active cooling module. The intensifier inside of the pressure vessel is shown on FIGURE 2. By changing the geometry of heat exchanger, we can intensify the heat removal from the storage and thus improve the process of hydrogen absorption into the structure of metallic alloy. When designing passive cooling modules, the condition that the ratio of metal hydride storage capacity to aluminium volume is maintained must be considered. The intensifier is best made of aluminium due to its good thermal conductivity ($\lambda = 237\ \mathrm{W.m^{-1}.K^{-1}}$).

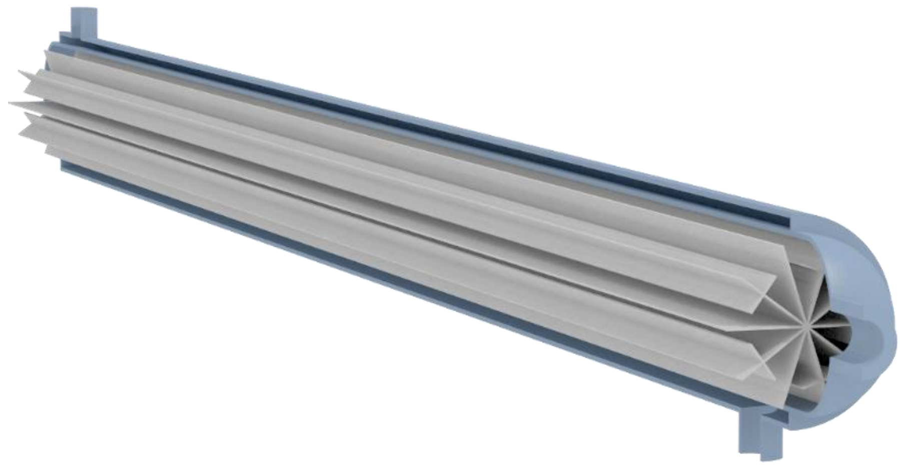

FIGURE 2: Internal heat exchanger inside of metal hydride vessel

Figure 3 shows the design of the geometry of the internal heat exchanger in its cross section. This geometry consists of 8 primary lamellas and 8 secondary lamellae. The secondary lamellas are connected to 4 main ribs. Auxiliary lamellas are placed every 45°. The gap between the intensifier and the shell wall is 1 mm.

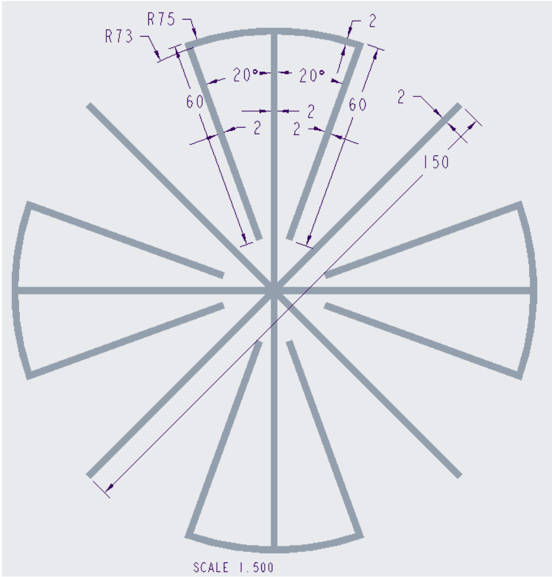

FIGURE 3: Cross-section of internal heat exchanger

V. HEAT TRANSFER ANALYSIS OF DESIGNED INTERNAL HEAT EXCHANGER

This chapter describes simulations by using finite element method by using program called ANSYS CFX. Numerical solution by using finite element method of such problems is currently the most efficient. Solving problems that involve se

Numerical solution using finite element method of such problems is currently the most efficient and universal way. Solving problems that involve complex and difficult geometry with different materialistic properties is impossible to solve analytically. The finite element method is used to solve problems in the field of fluid flow and heat transfer. The method is based on that the examined model is divided into finite number of volumes and subsequent calculation takes place over the boundary points of these volumes.

The simulations are focused on heat dissipation from the core of the metal hydride pressure vessel. Heat dissipation by means of a coolant along the outer surface of the casing is also investigated. All simulations are solved in ANSYS CFX program as 2D tasks.

The internal heat exchanger design is made from fourteen lamellas, where the four main lamellas are connected by eight secondary lamellas near the wall of the pressure vessel. The other four auxiliary lamellas are spaced by 45°from each main lamella.

Next step of setting up simulation is to create domains and boundary conditions that will affect the final calculation. First boundary condition is that the pressure vessel is cooled around the primary pressure vessel where metal hydride is located by temperature of 20°C and has flow speed of $0.3 m \cdot s^{-1}$. On the outlet of cooling liquid, we considered the temperature of approximately 22°C. Heat transfer coefficient between the vessel and cooling liquid was calculated to simplify the final calculation. Next boundary condition was to set up materialistic properties of used metal hydride material (Ti Fe) in simulation and those are:

- Molar weight – 62,55 $kg \cdot kmol^{-1}$,
- Bulk density – 3250 $kg \cdot m^{3}$,
- Specific heat capacity – 430 $J \cdot kg^{-1} \cdot K^{-1}$,
- Thermal conductivity– 1 $W \cdot m^{-1} \cdot K^{-1}$.

Time of the filling of the vessel is 1200s.

In figure 4 is cross-section temperature field in the pressure vessel. The maximum temperature by metal hydride during the simulation is 93.34°C. The created temperature field shows that the metal hydride is overheated in 4 spots between main lamellas and auxiliary lamellas which makes them not efficient enough. At the beginning of the simulation according to the course of maximum temperature (Figure 5), temperature rises rapidly and gradually stabilized towards the end of simulation. The course of minimum temperature from the middle of the simulation is linear.

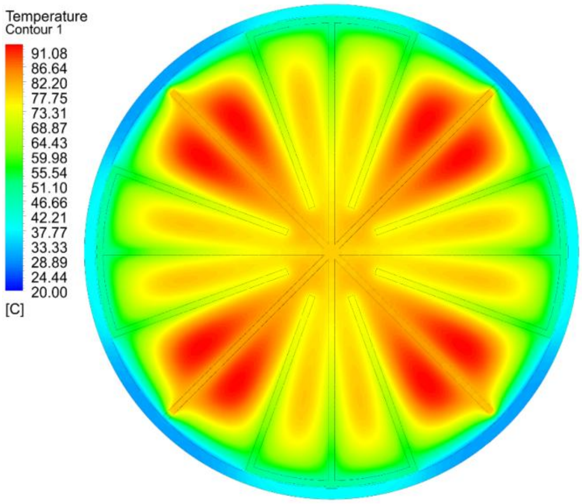

FIGURE 4: Cross-section temperature field of the pressure vessel

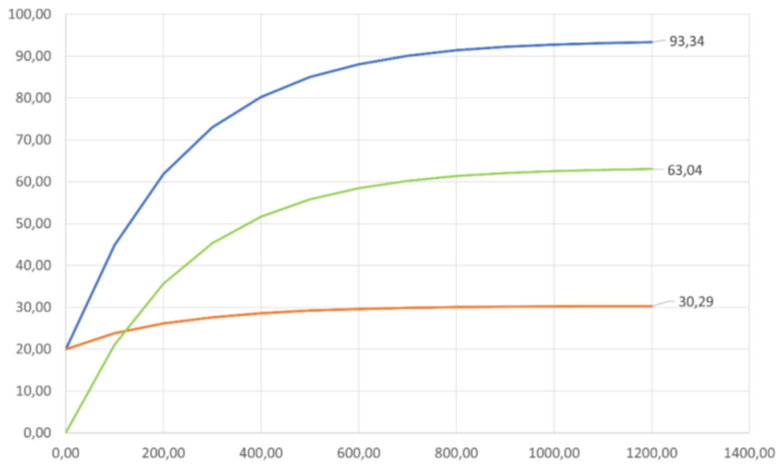

FIGURE 5: Maximum (blue) and minimum (orange) vessel temperatures courses and ΔT course (green)

The heat dissipation by cooling the metal hydride vessel in this simulation is shown in Figure 6. From the results of this simulation auxiliary ribs do not dissipate heat efficiently. The largest amount of heat is removed from the storage in the places of the main lamellas.

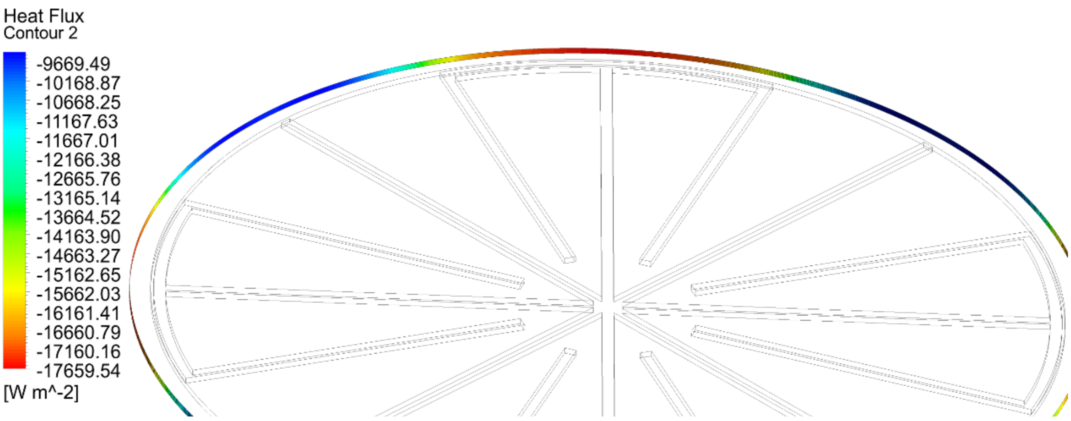

FIGURE 6: Heat dissipation by cooling

The cooling power that we can see in the picture has the largest value at the end of the simulation and its value is 6.76 W. This power is calculated per 1 mm of model thickness.

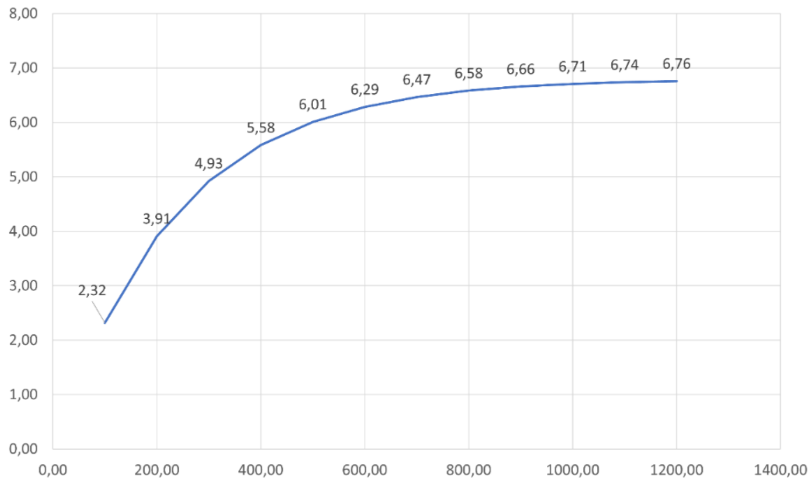

FIGURE 7: Course of cooling power over time

VI. CONCLUSION

Storing hydrogen in metal hydrides present very promising future since high pressures are not required. Only disadvantage of storing hydrogen in metal hydrides is requirement of heat dissipation, which is generated by metal hydride absorbing hydrogen. This is the main reason why active and passive cooling systems needs to be provided to the metal hydride pressure vessel. This article shows the design of passive cooling system implemented in metal hydride pressure vessel and heat transfer calculation. The results shows that auxiliary ribs do not dissipate heat efficiently which means, that metalhydride is overheated in those places. To get more satisfactory results, geometry of heat transfer exchanger needs to be changed. For instance, the placement of auxiliary lamellas can change the whole outcome of the simulation.

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