Structural Design of Atypical Metal hydride Tank and Investigation of Generated Temperature Fields: Part II

Filip Duda[1], Natália Jasminská[2], Peter Milenovský[3]

Department of Power Engineering, Faculty of Mechanical Engineering, Technical University of Košice, 042 00 Košice, Slovak Republic
*Corresponding Author

Received: 02 November 2023/ Revised: 12 November 2023/ Accepted: 19 November 2023/ Published: 30-11-2023

Abstract— *In part 1 of the article, temperature fields generated in a metal hydride tank of an atypical shape were investigated, where the tank was immersed in a cooling liquid. For the total temperature in the storage tank to be reduced even more, it is necessary to design an effective passive heat exchanger system that will remove this generated heat towards the inner wall of the storage tank, where this heat will then be effectively removed by the cooling liquid located on the outside of the storage tank. In part 2 of this article, an internal heat transfer intensifier is designed and subsequent verification of temperature fields using simulation in the ANSYS CFX program.*

Keywords— Metal hydride, pressure tank, heat transfer.

I. INTRODUCTION

Hydrogen as a safe, clean, efficient and energy carrier is a suitable candidate for reducing and eliminating greenhouse gas emissions. Hydrogen storage technology, which is one of the key challenges in the development of the hydrogen economy, is being addressed by the continuous efforts of scientists. Progress in hydrogen storage technology research and the latest developments in hydrogen storage materials are recorded. Common storage methods such as high-pressure gas or cryogenic storage cannot meet future storage requirements. Therefore, relatively advanced storage methods such as the use of metal hydrides and organic structure and carbon materials are being developed as promising alternatives. The combination of chemical and physical storage of hydrogen in certain materials has potential advantages among all storage methods. Metal hydrides have been intensively investigated to improve their pressure, hydrogen storage capacity, kinetics, cycle stability and thermal response, which depend on the composition and structural properties of the alloys.

The biggest disadvantage of storing hydrogen in metal hydrides is their weight and the need to create an efficient system for cooling the tank, because during the process of absorbing hydrogen into the structure of the metal alloy, heat is released, which reduces the amount of stored hydrogen and reduces the kinetics of absorption. Therefore, research on the cooling system within this hydrogen storage method is essential.

This work deals with the design of a hydrogen storage system in a metal hydride storage tank of an atypical shape with the help of a passive internal heat transfer intensifier, with the help of which the generated heat is removed towards the inner wall of the storage tank, where a storage tank effectively cooled by a cooling liquid is designed.

II. STRUCTURAL DESIGN OF AN ATYPICAL METAL HYDRIDE STORAGE TANK

The atypical tanks consists of three main parts, namely three cylindrical seamless pipes with a diameter of 60.3 mm with a wall thickness of 2.6 mm, two bottoms of an atypical shape, one of which has two holes with supply of hydrogen to the tank, on the holes there are flanges with a 1/4" NPT thread and inside the cylindrical tubes there are a heat transfer intensifiers for efficient removal of the generated heat to the inner wall of the tank, where the heat is subsequently cooled by the cooling liquid. The seamless pipes and bottoms of the atypical tank are made of 316L-1.4404 steel, where this steel is suitable for hydrogen applications based on the STN EN 13322-2 standard. The material and mechanical properties of the selected steel are shown in TABLE 1.

The structural design of the internal heat transfer intensifier consists of three primary ribs on which there are protrusions with a length of 5 mm and a thickness of 1 mm and three secondary ribs with no protrusions. The ribs of the designed intensifier describe a circle with a diameter of 52 mm and thus there is a gap of 1.5 mm to the inner wall of the tank. The intensifier is made of aluminum because it has good thermal conductivity. The heat generated in the metal hydride during the process of hydrogen absorption into its inner structure is approximately 1 MJ per 1 m3 of stored hydrogen.

FIG 1 shows the structural design of an atypical tank and FIG 2 shows the structural design of the internal heat transfer intensifier.

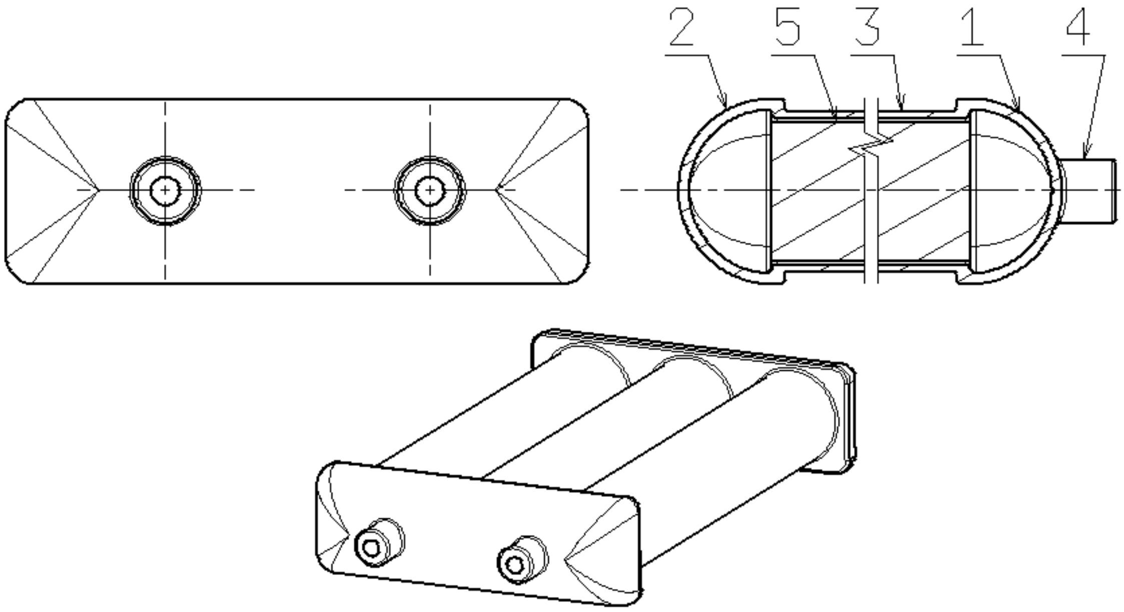

FIGURE 1: Structural design of an atypical metal hydride storage tank

Where: 1- Bottom of atypical shape with two holes for hydrogen supply, 2- Bottom of atypical shape-cap, 3-cylindrical seamless pipes, 4- Flange with 1/4" NPT thread, 5- internal heat transfer intensifier

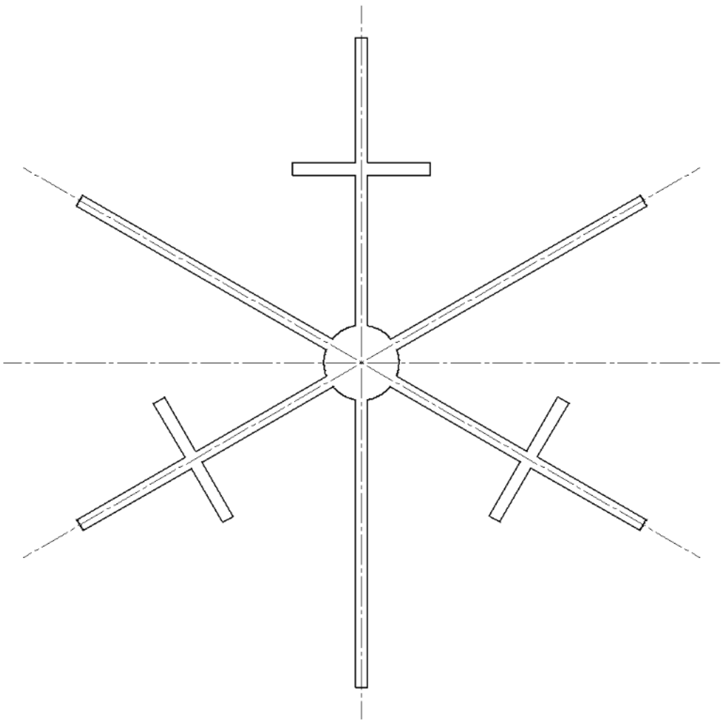

FIGURE 2: Structural design of the internal heat transfer intensifier

TABLE 1
MECHANICAL PROPERTIES OF STAINLESS STEEL 316 L-1.4404

0.2% Re (MPa)	Rm (MPa)	ρ ($kg \cdot m^{-3}$)	μ	E (MPa)
205	515	7950	0.3	$2.1 \cdot 10^5$

Where: Re-yield strength, Rm-strength strength, ρ-density, μ-Poisson's number and E-Young's modulus of elasticity.

The operational characteristics of the designed tank with internal heat transfer intensifiers are shown in TABLE 2.

TABLE 2
OPERATIONAL CHARACTERISTICS OF THE DESIGNED ATYPICAL RESERVOIR WITH INTERNAL HEAT TRANSFER INTENSIFIERS.

The weight of empty tank	5,7 kg
Weight of metal hydride	7,94 kg
Total weight of filled tank with MH	13,64 kg
Volume of metal hydride	0,0028 m3
Stored hydrogen mass	0,105 kg
Hydrogen volume	1,25 m3
Generated heat in tank	12500 kJ

III. SIMULATION OF THE HEAT TRANSFER OF THE DESIGNED TANK OF ATYPICAL SHAPE WITH AN INTERNAL HEAT TRANSFER INTENSIFIER

In the following section, the problem of heat transfer in the designed atypical tank is solved, where heat is generated through hydrogen refueling into the structure of the metal alloy. This generated heat must be dissipated and cooled to increase the kinetics of hydrogen absorption and, in addition, to store a larger amount of hydrogen in the structure of the metal alloy. The way in which it would be possible to cool the tank is, for example, to immerse the entire tank in the cooling liquid, which would, however, only cool the perimeter of the tank. The result of this simulation is shown in FIG 3.

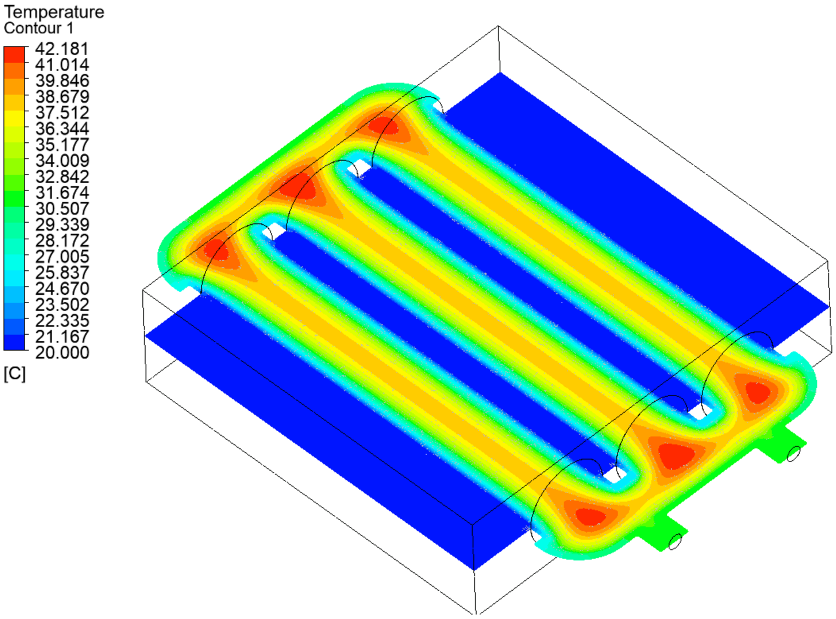

FIGURE 3: Generated temperature fields for an atypical reservoir immersed in a coolant.

To effectively remove the heat from the tanks core, it is possible to use a passive heat exchanger or an internal heat transfer intensifier, which will be in cylindrical seamless pipes. The intensifier serves as a passive cooling element, which means that the heat generated in the core of the tank is dissipated outwards in the direction of the ribs to the inner wall of the cylindrical seamless pipes, where this heat is then effectively cooled by the cooling liquid.

3.1 Setting up the heat transfer simulation of the storage tank with an internal intensifier

In this simulation, the temperature fields that arise on the entire volume of the atypical metal hydride reservoir will be investigated, and the temperature fields in the section of the cylindrical parts, where the internal heat transfer intensifier is located, will also be investigated. The process of hydrogen absorption into the structure of the metal alloy normally takes about 20 minutes when using an alloy based on LaCeNi, which also represents the total simulation time. Before starting the simulation, it is necessary to create a simulation model and generate a mesh of finite elements. Generated mesh represents approximately 7,000,000 nodes and 1,500,000 volumetric finite elements.

Another part of the simulation setup is defining the boundary conditions. The first step is to define the domains that define the overall simulation model. Specified domains include steel tank, metal hydride alloy, heat transfer intensifiers, and coolant. It is further necessary to define the initialization conditions for each domain, i.e., the initialization temperature is set to the ambient laboratory temperature, which is 20°C. In the domain of the cooling liquid, it is necessary to define the inlet and outlet of coolant, and in the domain of the metal hydride, it is necessary to define the heat generation power during the hydrogen absorption process. The power value is set to 107·103 W·m-3.

Another thing that needs to be done before starting the simulation is to define the material properties and individual connections between the defined domains. FIG 4 shows the prepared simulation model.

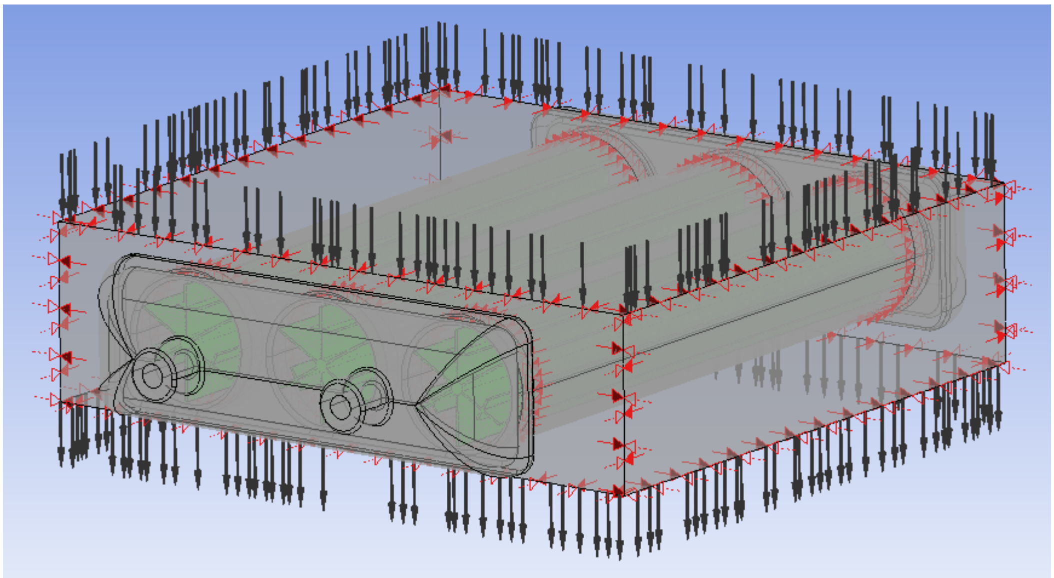

FIGURE 4: Finite element mesh of the first simulation

3.1.1 Simulation results

The maximum temperatures that occurred in the tank were mainly in bottoms, where they reached a temperature of 42.1°C. However, the average temperature in the cylindrical parts of the tank, in which the heat transfer intensifiers were located inside, was approximately 28°C. This means that the kinetics of absorption as well as the amount of stored hydrogen will be higher than if the internal intensifier was not inserted. According to the PCI curve of the selected metal hydride alloy LaCeNi at the obtained temperature, the mass ratio reaches 1.8%wt.

By optimizing the geometrical shape of the internal heat exchanger, it is possible to reduce the maximum temperatures even more.

The result of the simulation of the temperature fields on the entire volume of the reservoir can be seen in FIG 5, and the result of the simulation of the temperature fields in the section of cylindrical seamless pipes with a heat transfer intensifier can be seen in FIG 6.

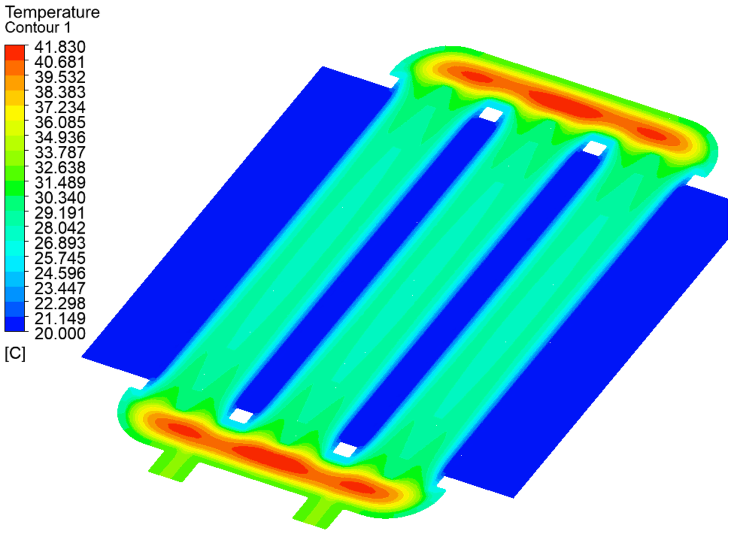

FIGURE 5: Generated temperature fields in an atypical metal hydride tank with heat intensifiers

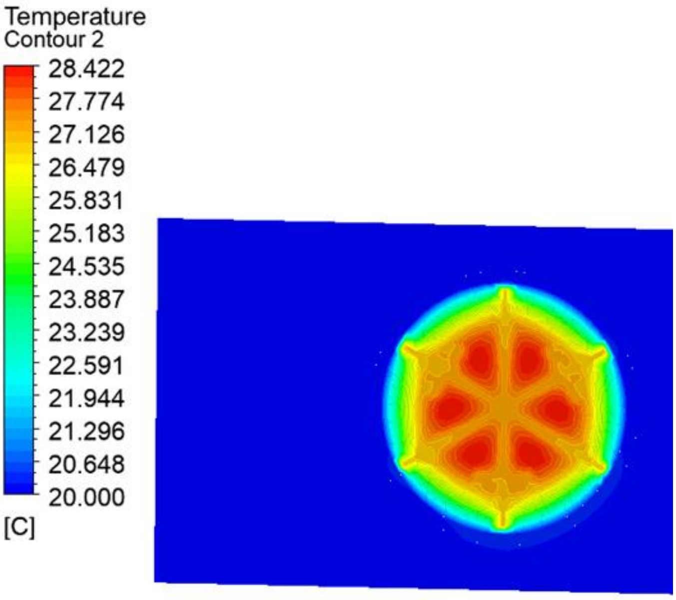

FIGURE 6: Generated temperature fields in the section of the cylindrical wall of a seamless pipe

IV. CONCLUSION

In the Part 1 article, the temperature fields where cooling of the designed atypical metal hydride tank was not considered were investigated to find the maximum generated temperatures that reached about 50°C. Subsequently, the investigated tank was immersed in the cooling liquid, which reduced the maximum temperature to approximately 41.5°C.

The aim of this article was to create an effective system for dissipating the generated heat from the core of the storage tank through a suitable passive cooler, i.e. an internal heat transfer intensifier, so that the maximum temperature of the designed storage tank could be reduced even more.

After the application of the internal heat transfer intensifier, the maximum temperature in the cylindrical parts was reduced to a temperature of 28.4°C, which significantly increases the kinetics of hydrogen absorption into the metal alloy structure. By properly optimizing the shape of the intensifier, it would be possible to reduce the temperature even more, which will be another part of the research.

ACKNOWLEDGEMENTS

This paper was written with financial support from the VEGA granting agency within the projects no. 1/0224/23 and no. 1/0532/22, from the KEGA granting agency within the project no. 012TUKE-4/2022 and with financial support from the APVV granting agency within the projects no. APVV-15-0202, no. APVV-20-0205 and no. APVV-21-0274.

REFERENCES

[1] Afzal, M. Mane, R. Sharma, P.: Heat transfer techniques in metal hydride hydrogen storage: A review. International Journal of Hydrogen Energy 42, 2017.

[2] Lipman, E. T., Weber, Z, A. Fuel Cells and Hydrogen Production. New York: Springer Science+Business Media, 2018. ISBN 978-1-4939-7789-5.

[3] Stolten, D. (2010). Hydrogen and Fuel Cells, Weinheim: Wiley, 2010, 908 p. ISBN 978-3-527-32711-9.

[4] Brestovič, T., Jasminská, N. Numerické metódy a modelovanie v energetike, Košice, SjF TU v Košiciach, 2015. ISBN 978-80-553-0223-2.

[5] Murín, Justín; Hrabovský, Juraj; Kutiš, Vladimír. Metóda Konečných Prvkov Vybrané kapitoly pre mechatronikov, Slovenská technická univerzita v Bratislave, 2014.

[6] Ravinger, Ján. Numerical methods in theory of structures, Slovenská technická univerzita v Bratislave 2014.

[7] Sankir, M a Sankir, D, N.: Hydrogen Storage Technologies. Scrivener Publishing LLC, 2018. ISBN 978-1-119-45988-0.

[8] STN EN 13322-2, Prepravné fľaše na plyny. Navrhovanie a výroba znovuplniteľných oceľových fliaš na plyny. Časť 2: Nehrdzavejúce ocele, 2003.

[9] Valizadeh, M. Delavar, A, M. Farhadi, M.: Numerical simulation of heat and mass transfer during hydrogen desorption in metal hydride storage tank by Lattice Boltzmann method. International Journal of Hydrogen Energy 41, 2016.