Design of Heat Exchanger for Low-Pressure Vessel for Hydrogen Storage

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Abstract— *This article describes the issue of hydrogen storage in metal hydrides and addresses the design of a heat exchanger and the calculation of heat transfer in low-pressure steel vessel with heat exchanger, which is used for hydrogen storage using La Ce Ni based metal alloys.*

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

I. INTRODUCTION

Following the problem of global warming, efforts have intensified to explore and implement alternative energy sources. At present, various political parties around the world are trying to raise awareness of renewable energy sources. In this context, hydrogen is considered a suitable candidate precisely because of its high heat value and good effects on environment. However, hydrogen is an energy carrier rather than source of energy, so it requires an efficient energy storage mechanism. There are several ways of storing the hydrogen, such as: high-pressure gas storage, liquid cryogenic storage, and low-pressure storage in metallic alloys. Low-pressure vessels are currently being developed for hydrogen storage. The main obstacle of the low-pressure vessels is the need to cool the alloys during hydrogen absorption and to heat the alloys during desorption.

II. DESIGN OF THE LOW-PRESSURE VESSEL

The design of the pressure vessel must be based by standard STN EN 13322-2. This standard is about transport gas cylinders, design and production of refillable steel gas cylinders. The construction of vessel consist of main body and casing for the flow of coolant and heating fluid as can be seen in Fig 1.

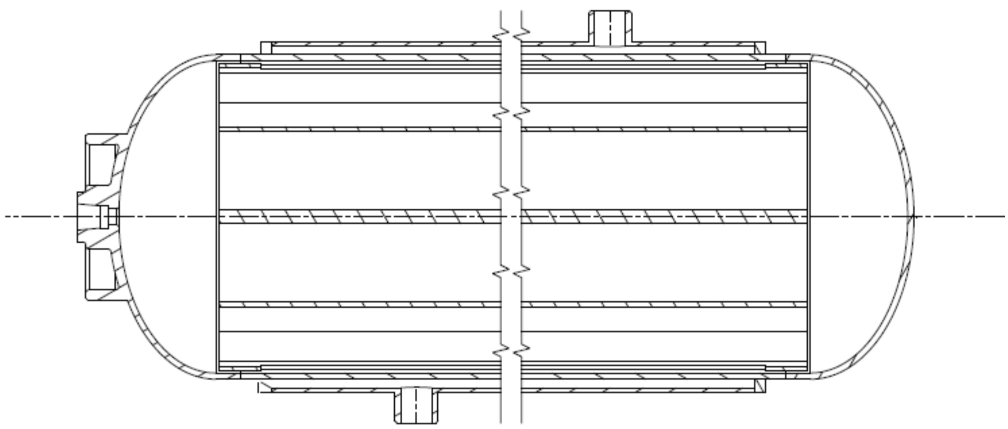

FIGURE 1: Design of low-pressure vessel

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	$2.1 \cdot 10^5$

Where Re- yield strength, Rm- tensile strength, ρ- density, μ- Poisson's constant and E- Young's modulus of elasticity

III. DESIGN OF THE HEAT EXCHANGER

The main task of this work is to design an internal heat exchanger to improve heat transport during the filling of the pressure vessel with hydrogen. The geometry design of the heat exchanger consists of five main fins and ten secondary fins. The secondary fins are connected to the main fins with circular section which copies the shell of the pressure vessel. This should increase the heat exchange area at the wall of pressure vessel. The gap between the heat exchanger and the pressure vessel is 1mm. The heat exchanger is shown in Fig. 2.

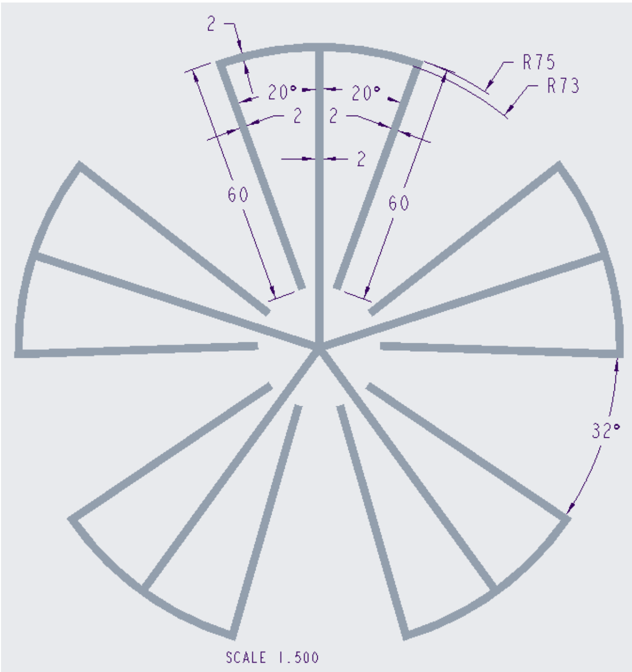

FIGURE 2: Cross-section geometry on heat exchanger

IV. SETTING THE SIMULATION FOR HEAT EXCHANGER

In this simulation we, will consider a heat exchanger that consists of ten main fins and ten secondary fins as shown on Fig. 2. The first step in setting up the simulation is to create a simulation model in Ansys Workbench. The simulation model consists of three main parts which are the metal hydride, heat exchanger and shell of pressure vessel. After creating each part of the model, it is necessary to generate a mesh for each part of the model as shown on Fig. 3. The next step of simulation is to define boundary conditions. During filling, the pressure vessel is cooled by water on its outer surface. It is assumed that the temperature of the water is approximately 20°C and flows at a speed of $0.3 m \cdot s^{-1}$. To simplify the simulation, we calculated the heat transfer coefficient between the pressure vessel and cooling water and thus obtained how much heat we can dissipate by water cooling, which we used as a boundary condition for heat dissipation to the environment. Subsequently, we defined a metal hydride material ($La_{0,85}$ $Ce_{0,15}$ Ni_5), which has the following properties:

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

The secondary fins are connected to main fins near the wall of pressure vessel. In the simulation, filling time 1200s is considered.

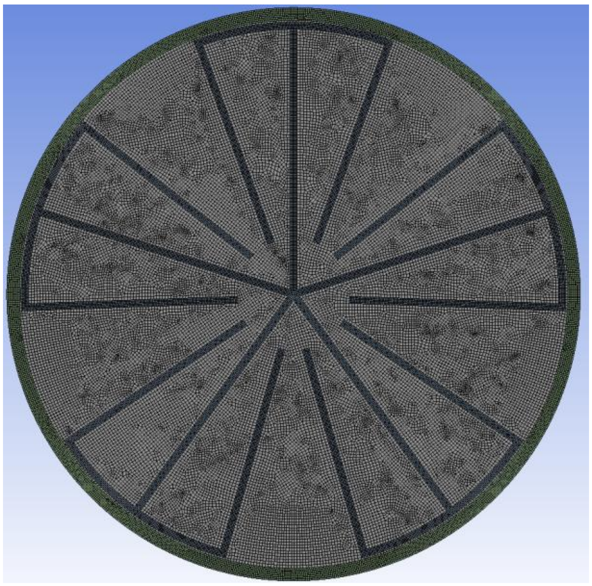

FIGURE 3: Generated mesh of the model for simulation

TABLE 2
SELECTED VALUES OF SIMULATION PARAMETERS TO CALCULATE INTERNAL SOURCE

Volume of metal hydride	$15\ 698\ \mathrm{mm}^3$
Mass of metal hydride	$51{,}0185 \cdot 10^{-3}$ kg
Mass of stored hydrogen	$7{,}295 \cdot 10^{-4}$kg,
Volume of hydrogen	$8{,}117 \cdot 10^{-3}\mathrm{m}^3$
Generated heat	8 198,26 J
Internal generated power	6,8318 W
Intensity of the internal heat source	$435{,}2\ \mathrm{kW} \cdot \mathrm{m}^{-3}$

In Fig. 4 we can see the design after defining all domains and boundary conditions as well as intensity of the internal heat source.

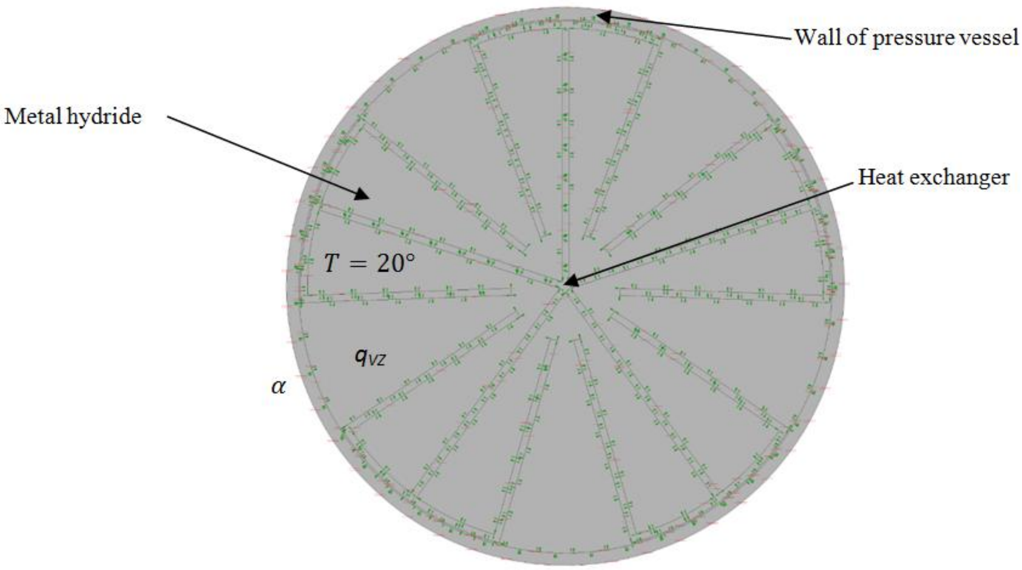

FIGURE 4: Boundary conditions of the simulation

V. RESULTS OF SIMULATION

The temperature field in cross-section view of the pressure vessel is shown in Fig. 5. The maximum temperature in pressure vessel after 1200s is 89.53°C. The warmest places in metal hydride are located between the secondary fins. The heat generated is well dissipated from the vessels core.

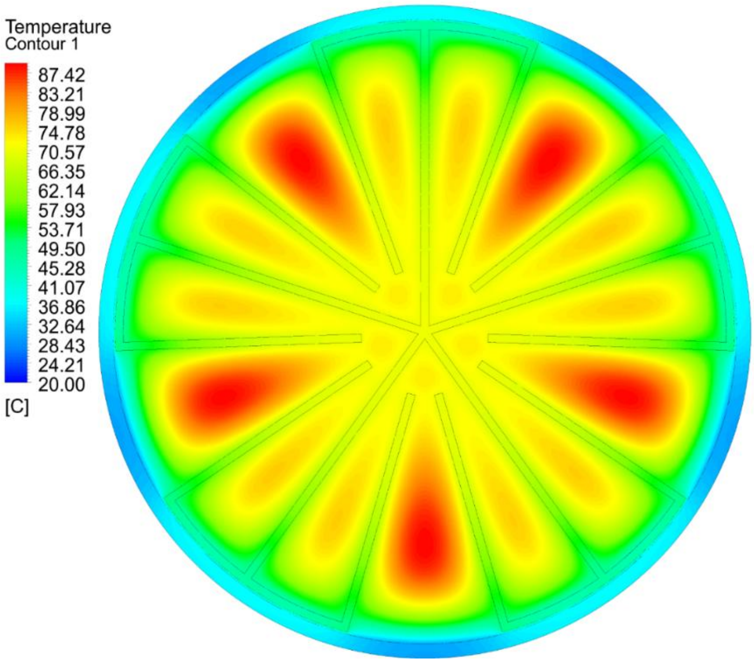

FIGURE 5: Temperature field of pressure vessel with heat exchanger

Fig. 6 shows the maximum and minimum temperatures over a period of 1200s. On the maximum temperature curve, we can see that during the last 200 seconds of the simulation it is almost stable. The minimum temperature curve does not change from the half of the simulation and remains at the same value till the end of the simulation. On Fig. 6 is also shown the course of the subtraction between the minimum and maximum temperatures (ΔT).

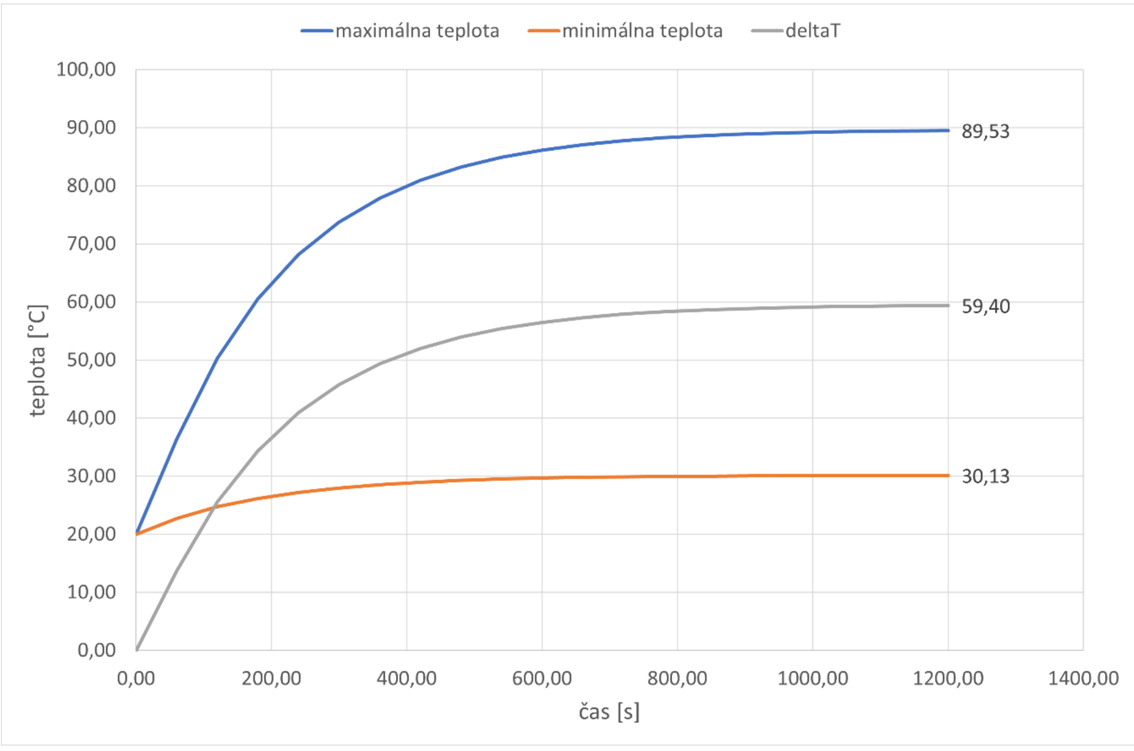

FIGURE 6: Courses of maximum and minimum temperatures in pressure vessel and course of ΔT

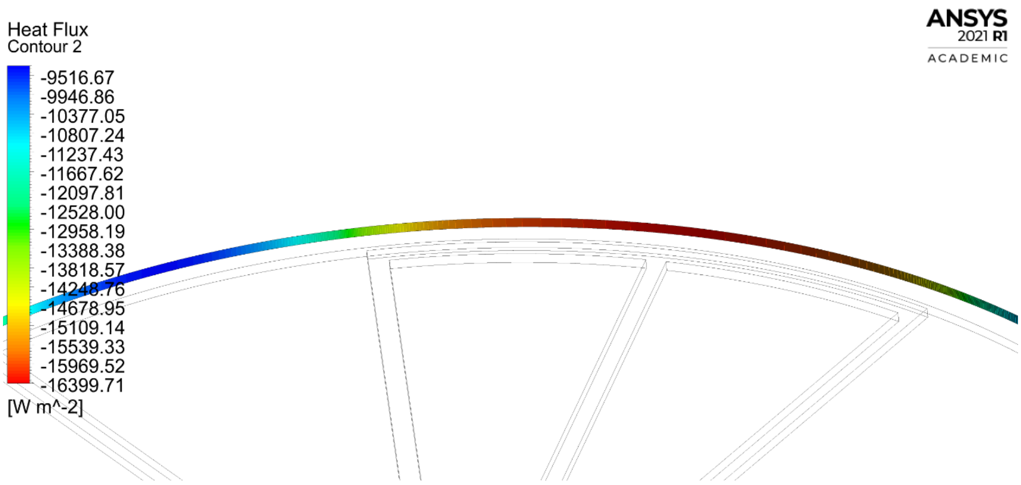

FIGURE 7: Heat dissipation by cooling

Fig. 7 shows the heat dissipation from the pressure vessel by cooling around the circumference of the steel shell. The highest values of heat dissipation are in the places where the fins are located, whether primary or secondary.

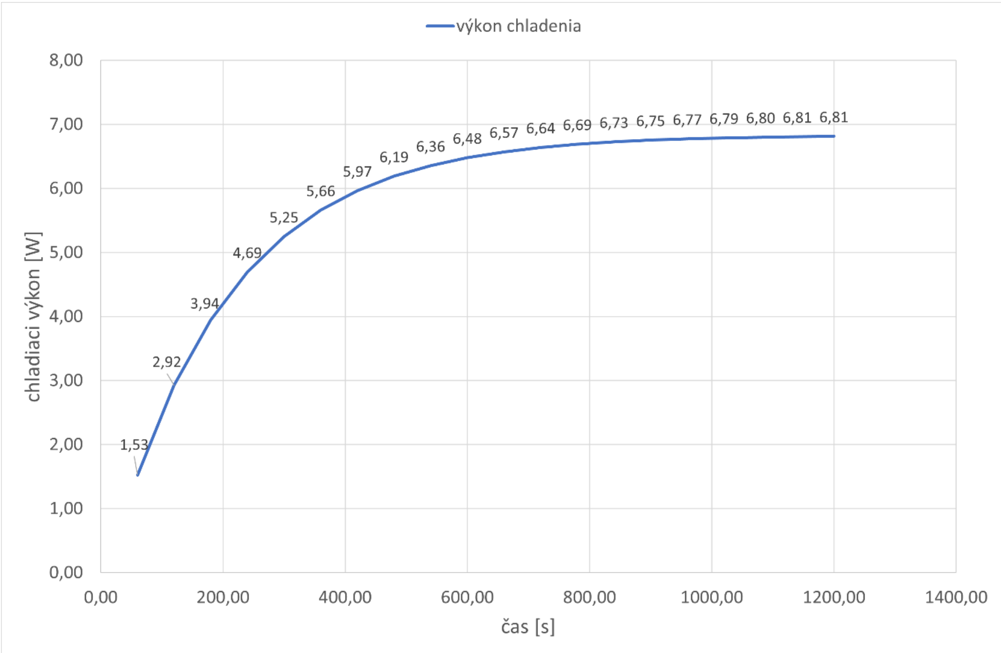

FIGURE 8: Cooling performance over time

Fig. 8 shows the water-cooling performance of the pressure vessel over the total filling time. The maximum value peaks at 6.81W per 1 mm of model thickness that was reached at the end of the simulation. We can observe that the curve stabilizes at the end of the simulation and does not have an increasing tendency.

VI. CONCLUSION

Hydrogen technologies represent a promising future in the automotive industry but also in everyday use. Hydrogen has a low bulk density and therefore must be stored in high-pressure tanks or in liquid form using cryogenic vessels, which makes these methods in terms of energy efficiency very demanding. From this point of view, the storage in metal hydrides may represent a promising future. When hydrogen is stored in metal hydrides, high pressures are not required, and they reach high values of bulk density. The disadvantages of storage in metal hydrides are the low bulk density in metal structure and the very low value of thermal conductivity of the used alloys. The aim of this work was to design a heat exchanger that will efficiently dissipate heat from the core of the pressure vessel to the outer jacket, where the vessel is cooled by coolant. The results of the simulation showed that the design of the heat exchanger achieved very satisfactory results and values in all aspects of the investigation.

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