Design of a Heat Exchanger for A Tubular Metal Hydride Storage Tank using Air as A Cooling Medium

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Abstract— *The article in question deals with the issue of cooling the designed tubular metal hydride storage tank with the use of active and passive cooling modules, which are implemented in the designed storage tank. The passive module used in the tank is realized by means of an aluminium heat transfer intensifier, which is placed directly in the metal hydride alloy of the tank, and as an active cooling module, air at a temperature of 10 °C is considered, and in the second simulation, an air temperature of 30 °C is considered.*

Keywords— Metal hydride, pressure tank, hydrogen.

I. INTRODUCTION

Sustainable energy conditions 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, the gradual transformation of which into a system characterized by a significant degree of carbon neutrality is currently highly relevant. Achieving a balance between carbon emissions and their absorption by natural systems requires a significant shift away from the use of fossil energy sources, a rapid increase in the share of renewable energy in total energy consumption, the continuous development of ecological technologies with a view to increasing 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 ecological non-fossil sources for its production, but also for efficient systems enabling its long-term and safe storage. Hydrogen storage is a very important component of the hydrogen economy system [1]. Currently, there are many ways to store hydrogen in the world, but the most common storage methods are through compressed gas or high-pressure storage, liquid storage of hydrogen through cryogenic temperatures or based on absorption into a metal alloy or low-pressure hydrogen storage. Hydrogen in the absorption method of storage forms metal hydrides with metals and alloys, which in some cases have a higher storage density than storage in pressure and cryogenic vessels. Storage in metal hydrides is a safer and volume-efficient form of storage. A metal hydride is formed by a host metal lattice and hydrogen atoms. However, this type of storage has its disadvantages, the biggest disadvantage being its weight within the system and at the same time the need to remove the generated heat during the exothermic reaction of hydrogen and metal hydride.

The article in question deals with the design of a heat transfer intensifier for efficient removal of the generated heat from the core of the tubular tank and subsequent cooling of the tank by means of a cooling medium located in the space between the primary tank in which the metal hydride is stored and the outer shell.

II. STRUCTURAL DESIGN OF A TUBULAR METAL HYDRIDE STORAGE TANK WITH AN INTEGRATED COOLING SYSTEM

The design considers a tubular tank, the diameter of the inner container with a metal hydride alloy is 60.3 mm. The dimensions of the tank, such as thickness, length and other dimensions, were determined based on the STN EN 13322-2 standard. The thickness of the tank wall is 2.6 mm. There is a metal hydride alloy inside the tank and a passive heat exchanger or heat transfer intensifier. On the surface of the tank shell, heat removal is ensured by means of a ribbed heat exchanger, where the heat is then removed from the surface of the ribs to the surrounding environment. In this cooling model, free convection is considered. In the design of the heat transfer intensifier, cross lamellas are considered, which gradually expand from the main axis. The primary lamellas of the intensifier describe a circle and the gap between the inner wall of the tank and the fin of the intensifier is 0.5 mm. The side secondary fins have a thickness of one millimeter, the length of which is from 7 to 12 mm. There are 6 primary fins and 18 secondary fins within the heat transfer intensifier system. In Fig. 1 shows the designed heat transfer intensifier in the cross section of the tank

Where: red colour represents the steel shell, brown represents the metal hydride alloy, and grey represents the internal heat exchanger

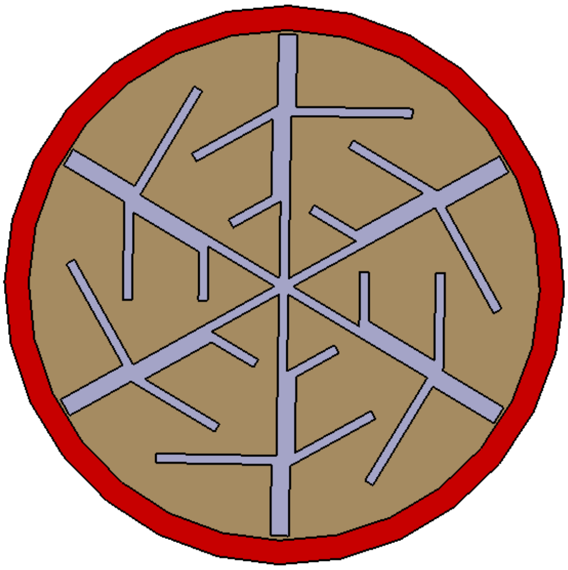

FIGURE 1: Designed heat transfer intensifier inside a tubular metal hydride tank

For the simulation, it is necessary to prepare a simulation model and therefore it is necessary to associate the external ribbing model with the model. The simulation model is shown in fig. 2.

Where: blue colour represents external ribbing

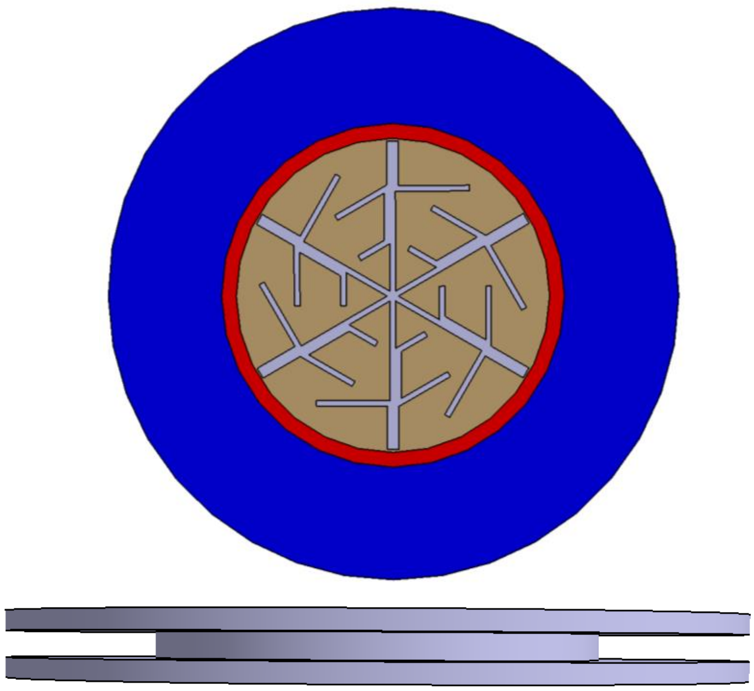

FIGURE 2: Simulation model of the system using an internal heat exchanger and a section of a part of the external ribbing

III. HEAT TRANSFER SIMULATION OF THE DESIGNED TANK USING THE CFX PROGRAM

In this section, the heat transfer simulation of the designed tubular storage tank is explained in detail, which uses an internal passive heat exchanger and uses an external finned system located on the outer wall of the storage tank shell. The cooling system is made of aluminum, the steel tank is made of stainless steel 316L. The tank contains a TiFe-based metal hydride alloy of the brand Hydralloy C5, whose maximum storage capacity is at the level of 1.8% wt. at room temperature. The simulation is set to 1200-time steps, where each step represents 10 s. The time 1200 s also represents the time of filling the tubular tank with hydrogen. Another condition that needs to be defined in the simulation is the power of the generated heat during the process of hydrogen absorption into the metal alloy structure.

To determine the power of the internal source of generated heat, the following equation must be used:

$$P = \frac{Q}{V \cdot t} \qquad (W \cdot m^{-3}) \tag{1}$$

Where: P- performance of the metal hydride alloy in the tank ($J \cdot m^{-3}$), Q- heat generated during the absorption of hydrogen into the metal hydride alloy (J)- 1 MJ of heat is consumed for 1 m^3 of stored hydrogen in the case of the designed tank, that is 0.5698 MJ, V- the volume of the metal hydride alloy (m^3) in the case of the designed tank, that is $1.18 \cdot 10^{-3}$ m^3, t- the time of filling the tank and this represents 1200s.

The intensity of the internal source of generated heat is therefore determined to be 401,730 $W \text{-} m^{-3}$. To simplify the simulation, the heat transfer coefficient on the surface of the outer ribs is determined by means of criterion equations for free convection, and the value of the coefficient is set to 25 $W \cdot m^{-2} \cdot K^{-1}$. The outside air temperature as a cooling medium was initially set to 10 °C and in the second simulation to 30 °C. The use of air as a cooling medium reduces the overall requirements for the design of the tank because, for example, if water were used as a cooling medium, it would be necessary to make a double-walled tank to create an intermediate space for water as a cooling medium, which would significantly increase the total cost of production. In the first simulation, it was considered without the use of the heat transfer intensifier, and the result of the simulation is shown in Fig. 3.

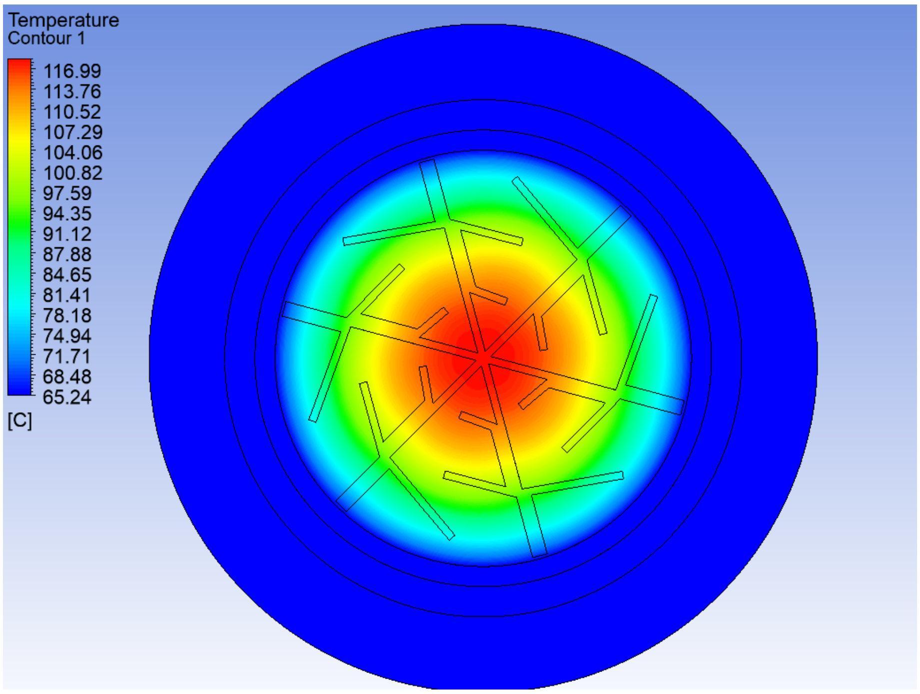

FIGURE 3: Generated temperature fields after 1200s of filling with hydrogen at an external temperature of 10°C without an internal heat transfer intensifier

The generated temperature in the tank without an internal heat transfer intensifier range in very high values up to 117 °C and thus the metal hydride alloy would not be able to absorb hydrogen into its structure because the limit temperature for absorption is approximately 75 °C.

In the second simulation, an internal heat transfer intensifier is applied, and the result of the simulation is shown in fig. 4.

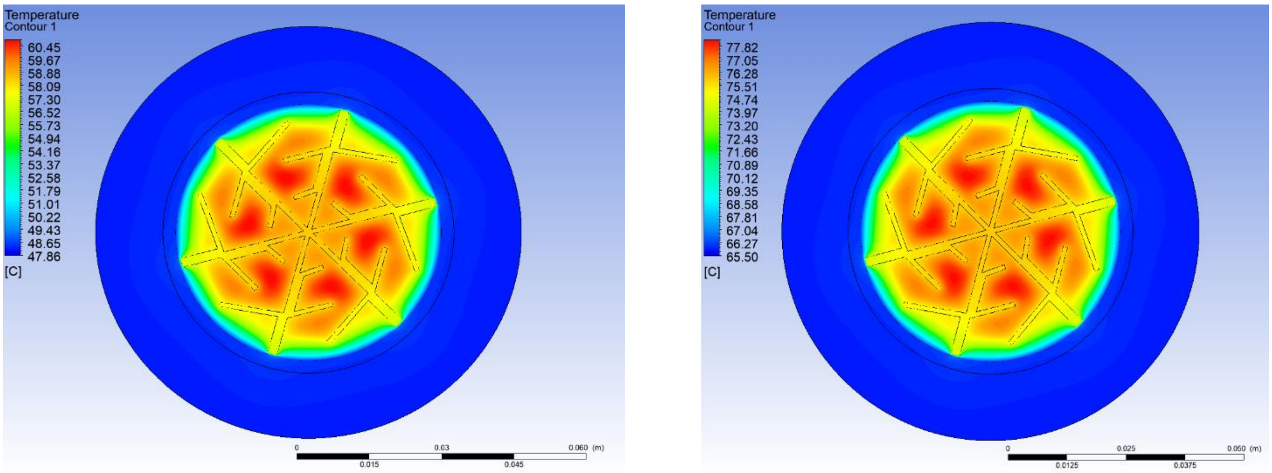

FIGURE 4: Generated temperature fields after 1200s of filling with hydrogen at an external temperature on the left side of 10 °C and on the right side of 30 °C with an internal heat transfer intensifier

The next step is to display the course of maximum temperatures in the tank during the process of filling the tank with hydrogen. Temperature curves are shown in Fig. 5.

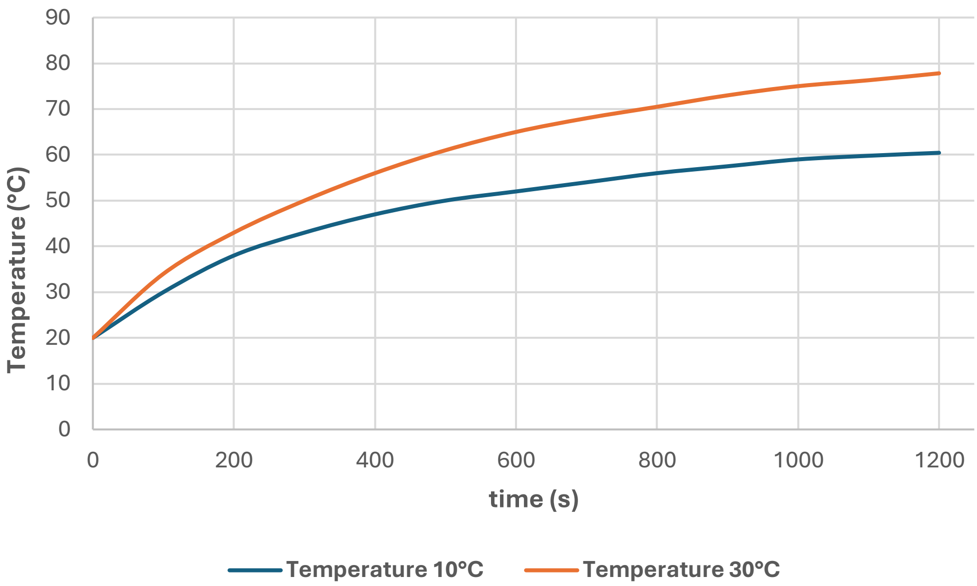

FIGURE 5: Course of maximum temperatures during the process of hydrogen absorption into the metal alloy structure at cooling air temperatures of 10 °C and 30 °C

Fig. 5 shows the temperature courses in the time interval 0 - 1200s when using an internal intensifier with cross-lamellas and an external heat exchanger ribbing. From the initial temperature of 20°C, the temperature of the tanks gradually increased according to the temperature of the cooling air to a temperature of 61°C at 10° C cooling air and to a temperature of 78 °C at 30 °C cooling air.

In the case of the use of outside ribs, it is also possible to observe the heat flow (Fig. 6) influenced by the presence of the individual ribs of the intensifier, but a more significant homogenization of the heat flow already occurs on the ribs.

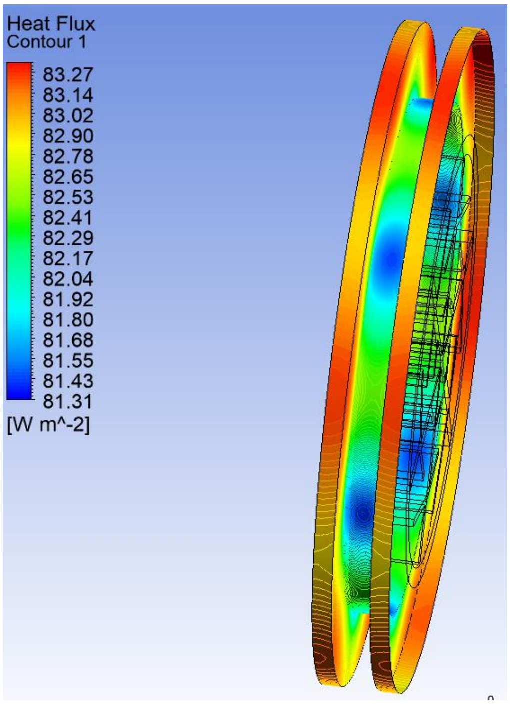

FIGURE 6: Heat flux of outside ribbing system

From the course of the simulations, it is obvious that without the presence of an intensifier in the tank, overheating of the core occurs, while the heat flow from the core to the surroundings is impaired, due to the powder structure of the metal hydride alloy. With the use of an internal heat transfer intensifier, in the case of an air-cooled tank, the heat distribution was stabilized within the entire cross-section of the tank, and the maximum temperatures generated on the tank comply with the operating parameters, as the limit temperature for the absorption of hydrogen into the structure of the selected metal alloy is 75 °C.

IV. CONCLUSION

The subject of this article was the creation of an efficient cooling system using the active cooling medium of air through external fins that were placed on the outer wall of the tank. The maximum temperatures during the process of absorption into the structure of the metal alloy at an air temperature of 10 °C created temperature fields of the metal hydride alloy at the level of 60 °C, and at an air temperature of 30 °C the temperature fields were at the level of 78 °C, which represents the limit temperature for the absorption of hydrogen into structure of the selected metal hydride alloy and thus it can be concluded that it meets the operating parameters. Based on the simulation, it is also possible to conclude that for the cooling of the tank system designed according to the STN EN 13322-2 standard, the use of external fins for cooling the system is completely sufficient, which reduces production costs.

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