HyCARE

Hydrogen CArrier for Renewable Energy Storage

Public summary D6.2

Design of Hydrogen-heat-storage module

Work package: 6

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Lead partner: HZG

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1. Introduction / Description

This report on optimized design of a hydrogen-heat-storage HyCARE module refers to the operational element designed and developed to absorb the hydrogen, store and release it. In addition to the H_2 connection and the balance of plant, the system is conceived to store and exchange heat internally.

To avoid confusion, a nomenclature has been developed, as represented in Figure 1.

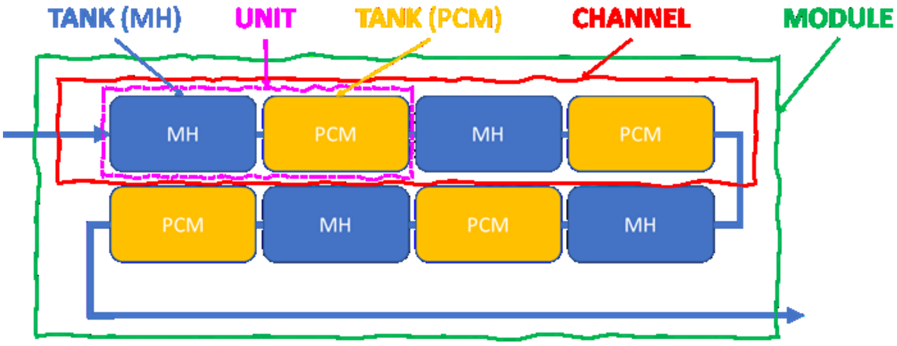

Figure 1 – Description and nomenclature of the elements in a module

The two tanks are defined as isolated containers for MH and PCM; in particular, the MH tank is a stand-alone pressure vessel that can be closed by valves. Together, a PCM and a MH tank form a *unit*, which is the smallest element that can represent the concept of HyCARE: hydrogen-heat-storage. More units can be arranged in series in a *channel*, and more channels or more units constitute a *module*, which is the minimum element that can be controlled in operation, from the point of view of hydrogen flow and thermal control.

2. Aim and Structure

The scope of this document is to describe the main features of the hydrogen-heat-storage module design under development in the framework of the collaborative project HyCARE. Specifically, it covers the aspects of the optimization process of the design, which have been discussed and studied step-wise, acquiring the available information from the other work packages, including the main requirements and boundary conditions contained in a preliminary risk analysis.

3. Regulations and Standards

All regulatory boundaries and technical standards already reported in previous documents apply to the design described in this document, as well as the technical and organizational measures suggested in the preliminary risk analysis to avoid the occurrence of dangerous situations and the general safety recommendations listed there.

In addition, to define dimensions, parts, and materials used in the design, the following standards are mentioned here:

- ISO 1127 – *Stainless steel tubes*
- EN 10216-5 – *Seamless steel tubes for pressure purposes - Technical delivery conditions*
- EN 10217-7 – *Welded steel tubes for pressure purposes - Technical delivery conditions*
- EN 1092-1:2013-04 *Flanges and their joints*
- DIN 28011 – *Torispherical heads*
- EN 10027 – *Designation system for steels*

4. Parameters

Main Parameters

The definition and setting of the main parameters of the system (enthalpy of absorption and desorption of the metal hydride, latent heat of phase change material, …) were the starting point for the development of the design. However, this apparently simple task was complicated and delayed by the experimental nature of some parameters, on one hand, and by the difficulty to retrieve final information about system component from the other hand.

Masses and Volumes

The hydrogen reversible capacity is very important, because it heavily influences the dimensions of the storage tanks and the quantity of necessary hydride to reach the goal of the project.

In any case, the actual status is fixed at about four tons of hydride powder, which can store between forty and fifty kilograms of hydrogen (according to the reversible capacity calculated in the range of temperature and pressure fixed as operative conditions).
This translates immediately in the mass requirements for the PCM, equating the heat exchanged between the abs/des in MH and the melting/solidifying in the PCM: the highest value for the metal hydride reaction enthalpy is during desorption, so the highest amount of heat exchanged is required during the desorption of hydrogen. From this value, dividing for the latent heat available during desorption (heat of crystallization, also the lowest between the two) the PCM mass was derived.

Activation Parameters

These parameters are a side topic, but they will influence several aspect of the design, because the activation procedure has to be performed inside the system. In fact, it is not possible to process that amount of powder outside the modules and to fill the system with activated and reactive powder. It is mandatory, in order to size the system to consider the maximum requirements. At the moment, further tests on activation are ongoing. Therefore, the system should be designed to endure at least the studied pressure and temperature; higher temperatures might be considered to compensate for issues in the heat management and distribution in the system.

5. Geometries and Design

Constraints

The constraints to the geometries are represented by the dimension of a 20 feet container, containing some insulation materials on its wall, and on the necessity to fit the storage systems within these boundaries.

It is still under discussion whether the BOP should be placed inside, if the final setting allow enough room for it, or if it must be placed outside the container in any case, to avoid the purchase and application of explosion-protected equipment.

From the practical point of view, the strictest dimensional constraint is the maximum length available inside the container. In fact, the insulation on the container wall is reducing the available dimensions, which for a standard container are: length ~5.8 m, width ~2.3 m, height ~2.3 m.

Development

The MH tanks must have a cylindrical shape to withstand the pressure, minimizing the wall thickness. PCM tanks were also cylindrical in the first attempt.

A different approach was then proposed: owing to the PCM not being under pressure, instead of a cylindrical container, it is possible to adopt a rectangular profile. This could fit between the MH cylindrical tanks, exploiting the dead volume left between the flanges. This solution is shown in Figure 2.

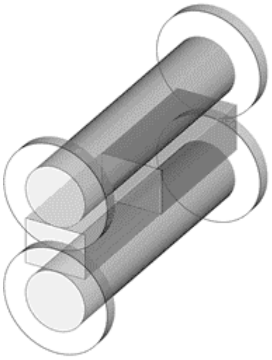

Figure 2 – Schematic view of the revised design.

Following this idea, several geometries for the PCM storage were discussed, performing calculations on the size of clusters of square pipes. The selected number of square pipes results in a length that leaves enough room for the connection of each pipe with the other.

At this point, the MH tank pipes specifications have been fixed, according to standards (EN 10216-5/10217-7). The flange (EN 1092-1) will be placed just one side and an end cap on the other side of the cylinder, with these advantages: less mass of steel to heat up during processes, less weight, and less volume occupied.

This means the heat exchange fluid connections will enter/exit the MH tank on just the flange side. It is suggested to have a simple internal heat exchanger, going through pellets parts. Depending on tests results, the pipe will go through the side of a part or its center; it is likely to be on the side, to avoid drilling the part or having internal friction when pressing in the dye.

The final geometries have to be easy for manufacturing and assembly, even if they do not reflect the best result of the simulations. The complex shape of the square pipes arrangement could be a problem for assembling everything in the container. For example, if H_2 is exchanged on the side of the tank, an access point is necessary; or the H_2 supply pipe can run parallel until an access point.

Considering the amount of space made available now from the absence of flanges for PCM, it appears possible to have once again a more simple rectangular packing of square pipes.

Design for Heat Exchange

To improve heat exchange, especially in the PCM tank, an internal heat exchanger with fins would be necessary in the former cylindrical design; the final tank design for MH and PCM will define the heat exchanger surface.

In case that complex shapes, like axial fin or radial fin pipes, are considered particular care has to be used for the MH. The loading of pellets inside the tank should not be hindered by heat exchange surfaces; even in case of the application of powder, this is very unlikely to distribute evenly between small gaps. It is discussed whether metal discs between the pellets could even help the handling in addition to the heat exchange. Considering the expansion of MH with absorption/desorption, also some kind of flexible material could help. From previous experiences at GKN on prototype pellets, an amount free space was necessary to expand in the radial direction. In addition, some free space has been also left in the axial direction. It has to be determined how to distribute the free space, in order to optimize the heat exchange and to minimize the mechanical stress due to MH expansion.

Considering the heat exchange with the PCM tank, the suggested design is not going to help for direct conduction/convection of the heat coming from MH to PCM, because of the losses and distribution of the square pipes. The use of the fluid for heat exchange allows a better control, but it has to be taken into account that some pipes are surrounded, while others have sides facing the insulation and this will lead to a heterogeneous behavior.

6. Materials

Details on materials for the construction of the tank and heat exchanger (PCM/MH) have been analyzed: a stainless steel is suggested for the external MH tank hull. Initially a stainless steel was suggested for the PCM tank as well, but during the development of the design, the use of square profiled pipes of aluminum has been preferred.

For this reason the internal heat exchanger in the PCM reservoir will be integrated in the aluminum profile; for the heat exchanger pipes of the MH tank the material is not yet defined, copper could also be investigated.

Mineral wool will be used for the insulation of the system, to prevent extensive heat losses.

7. Pipes and Instrumentation

Overview

The HyCARE hydrogen-heat-storage system consists of a complex system, composed by several units/modules linked together and connected with different loops, which will manage different fluids. Fluids involved in the system are the followings:

- Hydrogen gas
- Cooling/heating water-based solution
- Instrument air

The system will implement the recovery of the heat released during the H_2 absorption that will be stored in the PCM; this energy will be later used during the desorption phase. The lack of energy will be supplied by external source done by solar panels.

8. Energetic/Thermal Consideration

The melting rate of PCM has to be tested as compatible with the kinetics of hydrogen sorption in MH and the heat flows have to be designed carefully. In fact, considering the square pipes arrangement, or any other arrangement with those pipes, one drawback is the mass of aluminum resulting from the complex section of the pipes themselves. The increased mass, in addition to structural consideration, is resulting in an increased requirement for energy to heat up the system. Aluminium has a higher specific heat capacity than steel.

This has important consequences in the distribution of heat/temperature, but also in the control strategy of the system. If the hydrogen is absorbed in one tank at the time, so to exploit all the absorption thermal power to have a higher ΔT for heat exchange, the remaining tanks will cool down and will require again the energy to warm-up. Therefore, insulation will be very important.

Considering the possible strategies to assemble a complicated shape, involving separating in different blocks the complete tank, the use of PCM is important for its latent heat and less useful for its sensible heat. This means that it is important to melt as much as possible of it rather than overheat the first liquid fraction, while still having a solid fraction. Difficulties in this sense can arise from the viscous nature and the lack of empirical experience with this narrow gap of temperatures and available energies.

In the energy to warm up the system, the PCM sensible heat has also to be taken into account, so the modular approach for the control strategy will be verified in next steps.

A workflow is implemented in Figure 3 to proceed from the already available knowledge/data to the required parameters, especially to expedite the manufacturing of the prototype.

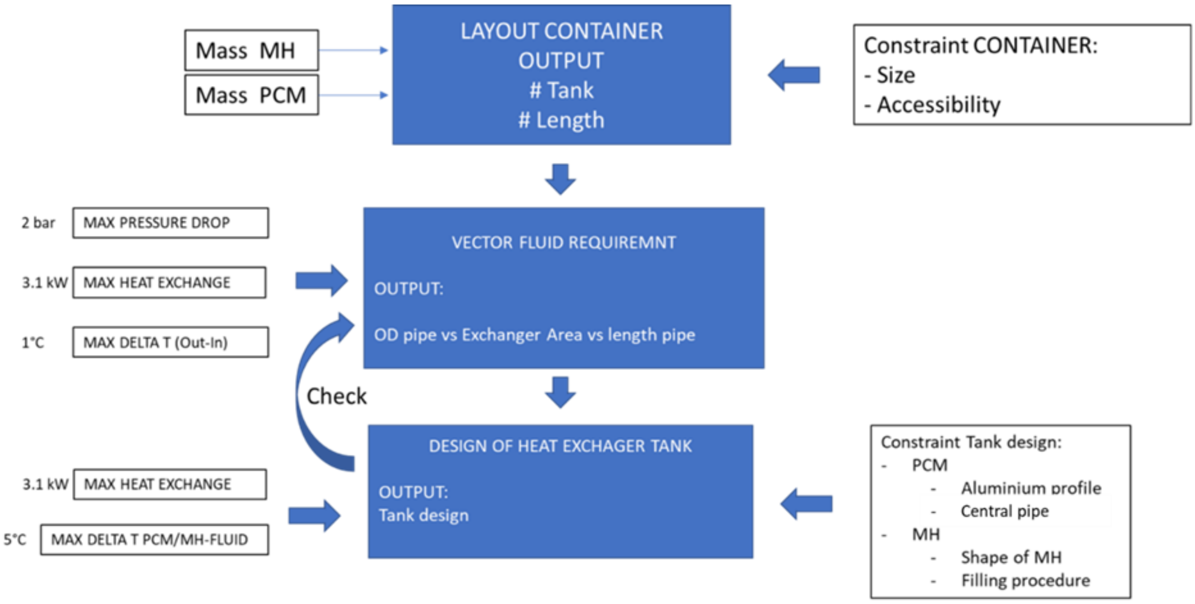

Figure 3 – Workflow to design the heat exchanger.

9. Conclusions

The final design of the module will be determined following the simulation and the validation of a first prototype, which is going to be built on the basis of the design and the considerations collected in this document.