Metal Hydride Hydrogen Storage Tank and its Certification for Use in Real Operations

Filip Duda[1*], Tomáš Brestovič[2], Marián Lázár[3], Natália Jasminská[4], Peter Čurma[5]

Department of Energy Engineering, Faculty of Mechanical Engineering, Technical University of Košice, 042 00 Košice, Slovak Republic Allen Kota, India

*Corresponding Author

Received: 01 November 2024/ Revised: 09 November 2024/ Accepted: 16 November 2024/ Published: 30-11-2024

Abstract— *The article discusses the issue of metal hydride tanks for hydrogen storage, their types, distribution and direct implementation of tanks in the real operation of equipment. The article also deals with certification and describes all the necessary tests established by the standards, which the designed metal hydride tank must successfully pass. The article also mentions the design of a tubular metal hydride tank, the outer diameter of which is 60.3 mm.*

Keywords— Metal hydride, pressure tank, certification.

I. INTRODUCTION

The lack of traditional energy sources in the form of fossils in the world leads to the research and development of other renewable energy sources. Hydrogen is an energy medium that is considered a renewable energy source, but hydrogen is considered an energy carrier. To obtain energy from hydrogen, it is necessary to use a suitable device that can obtain, for example, electrical energy from hydrogen. Such a device is called a fuel cell, which can be implemented in static or mobile applications in cars and other transport devices. For hydrogen technologies to be used in everyday life, continuous research and development must take place in several areas. The biggest challenges for the implementation of hydrogen technologies in everyday life are the production, distribution and storage of hydrogen. Efficiently storing hydrogen represents a key task for the implementation of hydrogen technologies in the transport sector. The storage of hydrogen is difficult mainly because of the very low volumetric energy density under standard conditions, as well as other demanding properties. Especially in the transport sector, for example for cars, buses, trains, ships and others, it is important to have hydrogen storage options with high volumetric and gravimetric energy density to be competitive with other conventional systems. For this reason, various hydrogen storage concepts and technologies have been developed in recent years.

The most common way of storing hydrogen in the transport sector is through high-pressure storage in the form of compressed hydrogen in a gaseous state. Hydrogen in such systems is usually stored in steel tanks at pressures from 15 to 20 MPa, but when using steel tanks, it is possible to achieve only 1.5 wt.% and 10-12 $kg \cdot m^{-3}$ gravimetric and volume density [1].

To achieve more optimal operating parameters of high-pressure systems, higher pressures are needed in tanks of 35-70 MPa, the value of the hydrogen mass fraction is 5.5 wt.% and 40 kg·m-3 gravimetric and volume density. For this reason, classic steel containers cannot be used, as the gravimetric storage capacity decreases at higher pressures. For higher pressures, it is necessary to use composite tanks reinforced with carbon fibers. From a safety point of view, this method of hydrogen storage is not the most suitable for implementation in the transport sector due to extremely high pressures [1],[2]. Another way to store hydrogen is to liquefy hydrogen using cryogenic temperatures. High values of gravimetric and bulk density can be achieved with this method. The pressure in the tanks is much smaller 1 MPa, compared to high-pressure hydrogen storage, where the working pressure ranges from 35 to 70 MPa. Tanks for storing liquefied hydrogen are mostly double shelled with insulation between them. To store hydrogen in this way, extremely low temperatures of 20 K are required, and for this reason this storage of hydrogen in the transport sector is very energy intensive.

Chemical storage of hydrogen in the form of metal hydrides represents a promising alternative for use in mobile applications. Metal hydrides are formed by hydrogen atoms dispersed in the crystal lattice of the primary metal. This storage of hydrogen allows for large storage densities because the hydrogen atoms have a strong interaction with the primary material. A great advantage of this storage is the possibility of storage at low pressures in ranges between 1-2.5 MPa at ambient temperatures. Although metal hydrides are extremely safe, there are also disadvantages that make further research and innovation in this area necessary. One of the disadvantages is the gravimetric energy density, which is very low, leading to a high weight of the metal hydride tank. Also, during the process of hydrogen absorption into the interatomic space of the metal hydride, an exothermic reaction occurs and thus heat is released, which is a disadvantage. For example, with an alloy based on LaCeNi, up to 1 MJ of heat is released for 1 m^3 of stored hydrogen [3].

This disadvantage must be solved by cooling the metal hydride alloy during the process of refuelling hydrogen into the metal hydride tank, which can be solved in different ways. Due to the cooling of metal hydride tanks, several types were created, while the basic geometric configurations of the tanks can be categorized into the following groups: disk, chamber or tubular tanks [4].

The most promising tanks for mobile applications are tubular. In this type of tank, a metal hydride alloy is poured into a steel tank and two basic types are distinguished. The first type represents tubular tanks, the diameter of which is less than 30 mm to allow sufficient heat transfer in the radial direction.

The second type represents tanks whose diameter is greater than 30 mm. For such tanks, the necessary cooling system is implemented on the metal hydride tanks. The cooling system can be solved through passive cooling modules or active cooling modules.

In the next chapter, the design of a tubular metal hydride storage tank with the outer diameter of 60.3 mm, is dealt with, and then all the necessary tests that the designed storage tank must pass are mentioned for tank to be certified for use in mobile applications.

II. DESIGN OF TUBULAR METAL HYDRIDE TANK

When designing a tubular metal hydride storage tank, the outer diameter of the tank is 60.3 mm. This means that for the given storage tank it is necessary to integrate cooling not only around the perimeter of the container, but also directly inside for efficient removal of the generated heat to the inner wall of the metal hydride storage tank. The cooling of the tank in question is solved by means of cooling modules. Active cooling is located on the perimeter of the tank in the space between the primary body and the case. Passive cooling is implemented using an internal heat exchanger that is inserted inside the tank. The maximum working pressure of the designed tank is 30 bars. The material used in the design of the tubular tank is stainless steel type 316L. Maximum thickness of shell of designed tank is set to 2.6 mm. The design of the tank is shown in Fig. 1.

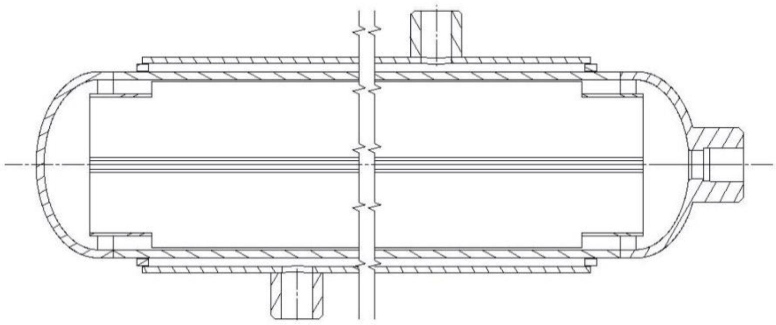

FIGURE 1: Designed tubular metal hydride tank

The given tank is verified by strength analyses using the FEM method. The maximum stress on the resulting tank at working pressure of 30 bars is 30 MPa, which is far less than the value of the yield stress of the selected material determined by the manufacturer.

Another part of this article is the listing and determination of all the necessary tests for the certification of the tubular metal hydride storage tank through the standard STN EN 13322-2 part 2.

III. TESTS FOR THE CERTIFICATION OF THE DESIGNED TUBULAR TANK

The STN EN 13322-2 standard, in addition to the structural design, also provides information on the actual construction and manufacturing of the newly designed storage tank and all the necessary tests that the designed storage tank must successfully pass.

When designing and manufacturing the designed tank according to the standard, the given tank must be made using seamless or longitudinally welded pipes with bottoms that are circumferentially welded. At the same time, it must be true that all welds on the structures can be checked with the naked eye. This means that the primary tank of the designed tank, which houses the passive internal heat exchanger and metal hydride alloy, must be a seamless pipe. The second shell of the designed tank, in the form of a case where the cooling liquid is located, can be made of longitudinally welded steel pipe. Based on the standard, it must also apply that longitudinal welded joints must be butt welds, of which there must not be more than one [5].

The components of the designed tank, such as the casing, which are directly part of the structure of the designed tank, and which are not subjected to pressure, must be made of steel compatible with the steel of the tank. In the case of the designed tubular metal hydride tank, the case is made of steel 1.4404/316L. At the same time, each accessory of the container must be designed in such a way as to allow inspection of the welds. The fittings must not be connected by means of longitudinal and circumferential joints and must be designed to prevent water ingress. All welds on the structure must have full penetration [5].

Before tests are carried out on the newly designed tank, it must meet the requirements mentioned in the design of the tank itself, that is, the thickness of the walls of the cylindrical part of the primary tank, the casing and the thickness of the elliptical bottoms of the tank must comply with Chapter 2 of the cited standard. At the same time, the inner and outer surfaces of the containers must be free of any defect that could make the containers in question unsafe to handle.

Standard STN EN 13322-2 describes a list of all necessary tests, namely: tensile test, brittleness test, impact test in bending, macroscopic inspection of weld cross-sections, hydraulic test on two tanks, radiographic, radioscopic or NDT inspection of welds on the structure, cyclic pressure test on one tank, corrosion test on one tank. All the mentioned tests must be carried out on the finished tanks after completion of all manufacturing processes, including cold forming at cryogenic temperature.

From a structural point of view, the most important are the cyclic pressure test and the hydraulic test until the tank breaks.

1.1 Cyclic pressure test:

This test must be performed on one manufactured tank. It must be done with a non-corrosive liquid, exposing the tank at the upper pressure of the cycle, which is equal to the maximum test pressure above atmospheric. The value of the lower pressure of the cycle must not exceed 10% of the value of the upper pressure of the cycle. The frequency of dead pressure must not be higher than 0.25 Hz, that is, 15 cycles per minute. The temperature during the test itself on the outer surface of the tank under test must not exceed a value higher than 50 °C.

The tank under test must be subjected to a minimum of 12,000 cycles without any leakage or structural failure. After the cyclic test is completed, the tank must be divided into several pieces to measure the wall thickness of the tank and at the same time to verify that this thickness is not more than 15% above the minimum thickness. The actual thickness of the tank wall must be recorded in the design test certificate.

1.2 Hydraulic test until failure:

The hydraulic failure test of the designed tank must be performed on a device that allows the pressure to be increased at a manually adjustable rate until the tank under investigation fails. When performing the test itself, the change in pressure as a function of time is recorded.

For a test pressure that is less than or equal to 60 bar, the failure pressure must be at least 2.25 times the test pressure above atmospheric. If the test hydraulic pressure is higher than 60 bar, the pressure must be 1.6 times the test pressure above atmospheric at failure. This means that the smallest possible overpressure in case of failure of the designed tank must not be less than 105.75 bar, because maximum test pressure over atmospheric is 47 bar.

No fragmentation of the material must occur during the test of the tank until failure. The main fracture after the pressure test must not show any brittleness, that is, the edges of the fracture must not be radial, they must show thickness contraction and at the same time they must be at an angle to the plane of the diameter. If the resulting fracture on the tank does not meet the above requirements, the tank must be resubmitted for further testing to decide on its acceptance or rejection.

IV. RESULTS OF HYDRAULIC TEST TO FAILURE AND CYCLIC TEST OF DESIGNED TANK

The result of the cyclic pressure test is shown in Table 1. The tank was cyclically loaded to the value of the maximum test hydraulic pressure, which was determined by the standard STN EN 13322-2 part 2. The value of the test pressure is 47 bar.

TABLE 1
RESULT OF THE CYCLIC TEST OF THE DESIGNED TUBULAR TANK

Total number of cycles (1):	15241
Average number of cycles per minute (min^{-1}):	9,15
Minimum pressure at the top dead centre of the cycle (bar):	48,6
Maximum pressure at bottom dead centre of the cycle (bar):	1,5
Maximum dead centre frequency (cycles/min):	9,5
Maximum temperature on the surface of the tank (°C):	33,2

From the test, the given tank complies with the condition set by the standard and even after 12,000 cycles, the given tank did not show any structural changes.

In Fig. 2 is the result of the pressure test until the tank breaks.

FIGURE 2: Result of hydraulic test until failure

At a pressure of approximately 500 bar, the test tank broke, which is almost 5 times of the smallest pressure for breaking the tank, which in this case is 105.75 bar. Based on the tests, it is possible to conclude that the designed tank meets the operating parameters, and it can be certified for implementation in real operation.

V. CONCLUSION

All necessary tests for certification according to standard STN EN 13322-2 part 2 were performed on the designed tubular tank. The tank successfully passed all tests, the most important of which were the hydraulic test until failure and the cyclic pressure test. Based on the results, the designed tank withstood 5 times the minimum required pressure until it ruptured and at the same time withstood more than 1200 cycles, which were determined based on the mentioned standard. The designed tank can be implemented in the real operation of the equipment, which will require a hydrogen storage system.

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-21-0274 and no. APVV-23-0266.

REFERENCES

[1] B.P. Tarasov, M.V. Lototskii, V.A. Yartys, Problem of hydrogen storage and prospective uses of hydrides for hydrogen accumulation. Russ. J. Gen. Chem. 77, 694–711 (2007)

[2] Z1uttel, A., Materials Today, 2003, September, p. 24., Dynetek. Asia-Pacific Natural Gas Vehicles Summit, Brisbane, Australia, April 10, 2001, Rene Rutz,VP Marketing and Business Development.

[3] Vinod Kumar Sharma; Metal hydrides for energy applications – classification, PCI characterisation and simulation, strany 901-923, Wiley Tóth, L., T. Brestovič a N. Jasminská.: Absorption of Hydrogen in the HBond©9000 Metal Hydride Tank, International Journal for Innovation Education and Research, 2018.

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

[5] Lin, H. Lu. S, Zhang, L. Recent advances in metastable alloys for hydrogen storage: a review, Rare Metal, 2022.