INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 39 (2014) 7365–7372

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

# Experimental study of metal hydride-based hydrogen storage tank at constant supply pressure

A. Souahlia, H. Dhaou*, S. Mellouli, F. Askri, A. Jemni, S. Ben Nasrallah

*Laboratoire d'Etudes des Systèmes Thermiques et Energétique, Rue Ibn Eljazzar, Ecole Nationale d'Ingénieurs de Monastir, University of Monastir, Monastir 5019, Tunisia*

ARTICLE INFO

*Article history:*
Received 11 December 2013
Received in revised form 14 February 2014
Accepted 19 February 2014
Available online 26 March 2014

*Keywords:*
Hydrogen
Metal hydride
Supply pressure
Cooling temperature

ABSTRACT

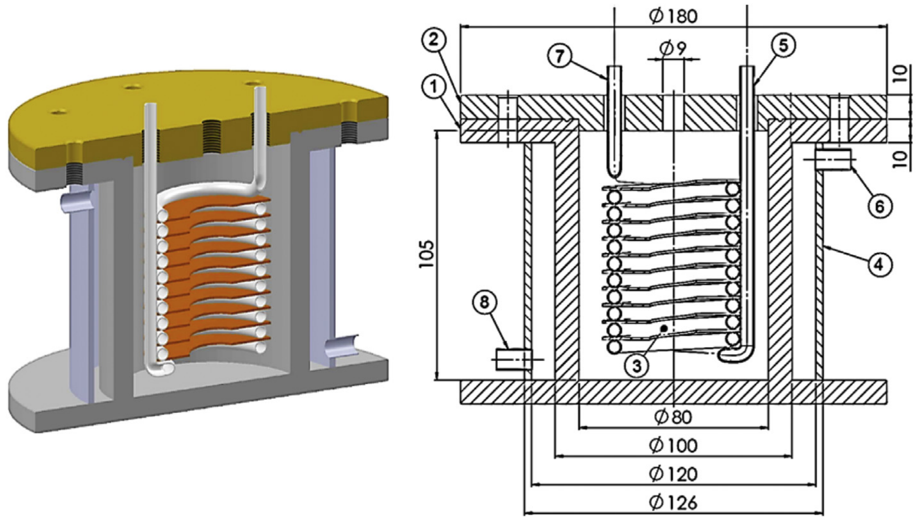
Metal hydride-based hydrogen storage tank is tested using 1 kg of $AB_5$ alloy, namely $LaNi_5$. The hydrogen tank is of annular cylindrical with inner and outer heat exchangers. The inner one is a finned spiral heat exchanger and the outer one is a conventional jacket. Performance (storage capacity and storage time) studies are carried out by varying the supply pressure and the cooling temperature of the hydride bed. At any given cooling temperature, hydrogen storage rate is found to increase with supply pressure. Cooling temperature is found to have a significant effect on hydrogen storage capacity at lower supply pressures.


## Introduction

Since environmental pollution proceeds from the large amount of fossil fuel energy consumption, new clean energy sources have been developed as alternatives. In addition, hydrogen is one of the most clean energy carriers. However, hydrogen storage and transportation become problematic. Among different hydrogen storage means (compressed gas, liquid hydrogen) reversible metal hydrides are considered as a safe and volume efficient hydrogen storage medium under low pressure conditions. Metal hydrides are generally used as packed beds. The metal hydride formation is closely related to the hydrogen pressure and bed temperature. Also, hydrogen absorption/desorption is an exothermic/endothermic reaction. Those phenomena and many others are complicatedly coupled together, so it requires a lot of experimental and theoretical works to optimize hydrogen metal hydride reservoir.

Suda and Kobayashi [1] performed a series of experimental studies on the hydriding and dehydriding kinetics for several alloys and their binary mixtures under isothermal conditions. They concluded that the mixing of hydriding materials offers several technical advantages such as controlling the reaction rate and the kinetic properties by varying the mixing ratio. Miyamoto et al. [2] investigated the reaction kinetics for $LaNi_5-H_2$ system under constant hydrogen pressure, and proposed the chemical reaction rate models. Goodell and Rudman [3] measured the intrinsic reaction rates for the hydriding and dehydriding of $LaNi_5$ over a wide range of pressures in the temperature range 60–65 °C. Approximately isothermal conditions were maintained by a thermal ballast technique. Later numerical models were developed for assessing the transient heat and mass transfer within metal

* *Corresponding author*. Tel./fax: +216 73501597.
E-mail address: dhaou_2000tn@yahoo.fr (H. Dhaou).
http://dx.doi.org/10.1016/j.ijhydene.2014.02.121




1. Tank shell
2. Lid
3. Finned spiral heat exchanger
4. Cylindrical jacket
5. 6. Water inlet
7. 8. Water outlet

**Fig. 1 – Schematic of the hydride tank.**

hydride beds [4–7]. It was found that the heat transfer plays a determining factor in enhancing the performance of storage tanks. For the sake of simplicity, these models neglected the convective effects of hydrogen gas on the heat and mass transfer, which however may be influential at high pressure cases.

From previous literature, the chemical reactions in metal beds may be simplified as a two-dimensional problem. Jemni and Ben Nasrallah developed two-dimensional heat and mass transfer models for hydrogen adsorption and desorption respectively [8,9]. The hydrogen flow motion within the hydride beds was described by Darcy's law. Their results show that the difference between the solid and hydrogen temperatures is negligible, except for some limited areas close to the gas outlet and tank wall. So the local thermal equilibrium hypothesis can be used. In a subsequent study, Ben Nasrallah and Jemni [10] further tested the hypotheses that were usually adopted in the analysis of heat and mass transfer in a metal hydride tank. They reached the conclusion that for an $LaNi_5$–$H_2$ reactor, (i) solid and gas temperatures can be treated as the same, (ii) the convection term is negligible, and (iii) the effect of hydrogen concentration on the equilibrium pressure variation is negligible in the absorption case, But in the desorption case this effect cannot be neglected in the determination of the temperature distribution in the reactor. The simplified numerical simulations were later compared with experiments and a good agreement is obtained [11,12].

Recently, Tange et al. [13] examined the feasibility of an onsite energy storage system using a tank packed with 50 kg of hydride metal, and discuss the energy efficiency of the system. This tank stores hydrogen at night and supply a fuel cells to generate power during the day. The system also utilizes the endothermic hydrogen desorption process for air conditioning. D'Orazio et al. [14] analyzed and reported the dynamic behavior of a metal hydride tank to propose a method to design a multi-tank storage system. The hydride tanks design and the heat flow are the key parameters for the optimization of the system working condition. Nyamsi et al. [15] conducted an analytical and numerical study to optimize a finned tube heat exchanger considering both enhanced heat transfer and metal hydride tank volume efficiency. It was shown that the fin dimensions, the cooling tube diameter and the fin length are the key parameters to reduce the thermal resistance of the heat exchanger. The results showed that the decreasing of the thermal resistance of 13% leads to a decreasing in charging time of 42%. Corgnale et al. [16] developed a scoping tool, referred to as the Acceptability Envelope, to identify the range of chemical, physical and geometrical parameters that allow a coupled media and hydrogen storage system to meet technical targets. Nam et al. [17] developed a three-dimensional model to study the hydrogen absorption reaction, heat and mass transport phenomena in metal hydride hydrogen storage tank. The simulation results demonstrate that the use of higher hydrogen supply pressure leads to not only rapid hydrogen charging performance but also a reduction in the cooling burden of the tank.

We studied, in previous work [18,19], the dynamic behavior of several metal hydride-based hydrogen storage tanks using a Sievert-type apparatus. We noticed that the reference volume variation influences the stored amount of hydrogen and the storage time. In order to have consistent measurements of a tank performances (storage time and storage capacity), the reference volume influence should be excluded. The solution would be to supply the tank with a constant hydrogen pressure. In this paper, a test bench was built to implement this solution. Also, a modified version of the metal hydride tank