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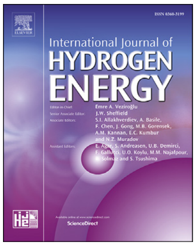

Experimental study of metal–hydrogen reactor behavior during desorption under heating by electromagnetic induction

Sihem Belkhiria [a,*], *Chaker Briki* [a], *Mohamed Houcine Dhaou* [b], *Nasr Sdiri* [c], *Abdelmajid Jemni* [a], *Faouzi Askri* [d], *Sassi Ben Nasrallah* [a]

[a] *Laboratoire D'Etudes des Systèmes Thermiques et Energétiques, ENIM, Université de Monastir Rue Ibn Eljazzar, Monastir 5019, Tunisia*
[b] *Department of Physics, College of Science-Qassim University, Buraydah Almolaydah, Buraydah 51452, Saudi Arabia*
[c] *Laboratoire des Matériaux Minéraux et Leurs Applications, Centre National de Recherches en Sciences des Matériaux, Technopole de Borj-Cedria, B.P. 95, Hammam-Lif 2050, Tunisia*
[d] *Engineering School University of Abha, Saudi Arabia*

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ABSTRACT

The objective of this work is to study experimentally the behavior of a metal–hydrogen reactor (MHR) during hydrogen desorption by the $LaNi_5$ hydride. The reactor is surrounded by a small coil traversed by an alternative sinusoidal current. The effect of the voltage applied to the coil is studied. Two kinds of tests are done. In the first one, the reactor is heated to the desired temperature and then it was put in contact with a tank at weak pressure (desorption), and in the second one, desorption and heating start simultaneously. Desorbed mass and temperature evolution within the hydride bed and in the reactor wall, as a function of time, are plotted. A comparison of results obtained by the electromagnetic induction heater and by heat exchanger provisioned by a hot fluid shows an improvement of the efficiency of the reactor when compared to the traditional hot system (fluid system).

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Introduction

The depletion of fossil fuels and the increasing of energy demand have prompted the international community to exploit renewable energies. Because of their intermittent characters, these energies require a storage system. The development of new energy storage technologies continues to interest researchers. Hydrogen, as a vector of energy, could emerge as a serious effective solution to use renewable energy and to save the world energetic system. While hydrogen can be stored as a compressed gas and cryogenic liquid storage, metal hydride is considered more promising because it provides a large hydrogen storage capacity at atmospheric pressure and temperature, consequently it's more secure than the gaseous and cryogenic storage systems [1–4]. The solid storage form is a very attractive way as it's safer and easier to manipulate than the gaseous and cryogenic storage. But its development is

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* *Corresponding author.*
E-mail address: sihembelkhiria@yahoo.fr (S. Belkhiria).

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limited by heat transfer problem within the hydride bed. Indeed, the absorption reaction is highly exothermic and the desorption one is endothermic [5]. As a result, we always need an external supply temperature of cooling (heating), in the case of absorption (desorption). Then, Dual-tuning effects of the thermodynamics and kinetics for hydrogen storage materials is one of the key issues for hydrogen economy and hydrogen storage materials. Metal hydrides are generally classified according to their operating temperature: low temperature (20–100 °C) or high temperature (200–400 K) [4]. Mahran Valizadeh et al. [6] show that the increasing fluid temperature greatly improves desorption kinetics of the $LaNi_5$ intermetallic hydride. Ha et al. [7] show that the hydrogen absorption by this intermetallic ($LaNi_5$) is governed by the heat transfer from the hydride bed to the cooling fluid surrounded the storage system. Desorption rate, as well as absorption rate, are highly dependent on the amounts of heat removed or provided to the metal–hydrogen system. Many researches show that the heat transfer is a very important phenomenon and must be taken into account to improve solid storage performance and therefore to develop efficient hydrogen reservoir. To enhance heat transfer within the hydride bed, and consequently, the performance of the hydrogen storage, it is necessary to optimize the design of the storage system and provide it by efficient heat exchangers. In general, the metal–hydrogen reactors can be classified into 3 categories: tubular, disk and tank or chamber reactor [8]. Among the conventional reactors, the ones which are equipped with a finned spiral heat exchanger present a better performance compared to other configurations [8]. An experimental and numerical study has been done by Demircan et al. [9] for two configurations storage system containing the $LaNi_5$ alloy. The first one is a cylindrical reactor cooled at its side surface and its base and the second one is formed by two concentric tubes and the powder is introduced in the space between the two tubes. In this case, in addition to cooling on the side surface, there is a heat exchange in the cavity of the inner tube. Ataer et al. [10] have shown that the reactor configuration of two concentric tubes present better hydrogen absorption rate then the cylinder one.

Mellouli et al. [11] have studied the effect of using a spiral heat exchanger to improve the heat transfer within the hydride bed. The experimental results shows that the charge/discharge times of the reactor are considerably reduced, when heat exchanger is used. Then, a mathematical model has been developed by the same research group [12] to evaluate the various designs of metal–hydrogen storage vessel. The results are compared with experimental data and it is found that the proposed model adequately captures the main physics of the sorption processes and can be employed for the design of a better metal hydrogen storage vessel. Mitsutake et al. [13] have investigated experimentally and numerically the possibility of equipping a storage system with longitudinal and radial spires.

Askri et al. [14] have compared numerically the hydrogen absorption rate related to four different configurations of hydrogen storage system: a cylindrical tank, a cylindrical tank with external fins, a cylindrical tank with a concentric tube filled with flowing cooling fluid and a cylindrical tank with a concentric tube equipped with fins. An experimental study has been presented by Dhaou et al. [15] to study the effect of a finned spiral heat exchanger on the heat and mass transfer within a metal hydrogen reactor. Jincheng et al. [16] have tried with a finned multi-tubular metal hydrogen tank, with different fins configuration, to improve the heat transfer within the hydride bed.

Zhen et al. [17] had performed a comparative numerical study on a magnesium-based material. Indeed, a comparison of desorption performance between three reactors, incorporating a conventional straight tube, fine tubes and a helical exchanger was realized. The results show that the helical heat exchanger reactor presents the best performance.

Hyum-gookang et al. [18] made a comparative experimental study between two small beds hydride, with a same simple cylindrical configuration, one contains 125 g of the ZrCo with copper foam and the other contains the same mass of the ZrCo with fine copper. Their results show that the performance of heat and mass transfer is more improved by using cooper foam. Indeed, the cooling is more efficient for the absorption and the heating is more uniform in the case of desorption. In the study of Garisson et al. [19] three designs of heat exchangers are investigated. The first one is a finned tube embedded at the center of the reactor, the second one is a vessel without an inner coolant tube and with externally finned radial wall that transfer heat to the ambient and the third one is a vessel with no coolant tube and without external fins on the radial wall. In the work of Raju et al. [20] three designs of heat exchangers have been studied numerically: a shell and a tube heat exchanger, an helical heat exchanger coil and a shell and a tube heat exchanger with alanate in tubes. Based on their evaluation, when using the second one, a higher heat transfer rate can be achieved. Meng et al. [21] have studied numerically and experimentally the using of a mini-channel reactor to enhance heat transfer performance for metal hydrides applications and their results showed that mini-channel reactors are suitable for achieving the optimum of heat transfer. Ben Mâad et al. [22] have developed a bidimensional mathematical model for predicting the coupled heat and mass transfer within a cylindrical hydrogen-metal reactor ($LaNi_5{-}H_2$) equipped by a change phase material (PCM) and their results show that the absorption occurs faster in the areas which are closer to the phase change heat exchange.

The works presented above focus essentially on the improvement of heat exchange between the hydride bed and the heater fluid coming from a thermostatic bath. In fact, their works are, generally, directed towards the elaboration of new heat exchangers configurations which are installed within the hydride bed. These exchangers allow a faster and more powerful heat transfer between the hydride bed and the heating fluid. Despite, all this methods considerably improves the heat transfer. But for low effective thermal conductivity of intermetallic hydrides, the heat propagation between hot fluid and the hydride bed is difficult. Heating is, then, not uniform within the hydride bed particularly when the reactor has an important mass. As a result, the reaction time is still long and there is a heat loss along the installation. On the other hand, desorption under a high temperature (>100 °C) needs a significant amount of energy. Also, the use of exchanger affects the capacity of the reactor in terms of storage capacity. In fact

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