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Review Article

Different reactor and heat exchanger configurations for metal hydride hydrogen storage systems – A review

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ABSTRACT

Recent work in hydrogen storage is mainly focused on implementing metal hydrides. Metal hydrides well demonstrated their high capacity for hydrogen storage within reasonable and safe pressures and temperatures. One of the effecting parameters on the performance of a reactor in a metal hydride hydrogen storage system is its design and configuration. There are a number of technical issues which need to be considered in designing a reactor. Some of these parameters are reactor configuration, thermal management, hydrogen transfer and mechanical strength. The current work is concentrated on the problem of thermal management while focusing on reactor and heat exchanger configurations. In this paper, different reactors and heat exchangers in metal hydride hydrogen storage systems are studied, categorized and compared. This classification helps the reader to find the best option for any specific application. However, for an optimum design of the reactor, in addition to the above noted parameters, other factors like coupling process of porous flow and reaction kinetics should be taken into account as well.

Contents

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Introduction

Hydrogen is a good option as an alternative fuel and energy storage medium due to its storage characteristics and its portability [1]. Although hydrogen suffers from low energy capacity per volume, it still offers the highest energy capacity per mass compared to fossil fuels [2]. An effective strategy to make the hydrogen economy more efficient is to recruit higher energy density hydrogen storing materials which have smaller volumes and less mass [2]. However, developing new materials or combinations of materials which exhibit high volumetric and gravimetric capacity, fast sorption kinetics at near ambient temperatures, and high tolerance to recycling still remains a main challenge for hydrogen storage systems [3].

Metal hydrides are compounds involving a host metal and hydrogen. They demonstrate good hydrogen storage properties in low pressures while the volumetric densities are comparable with liquid hydrogen. Hydrides are classified in two broad categories. The first, includes ionic and covalent hydrides. Ionic hydrides have hydrogen in the form of H^- and in covalent hydrides, the hydrogen shares the electron pair with non-metals or atoms with similar electro-negativities. The second, includes the metal hydrides with a hydrogen that acts as a metal. This type of hydride is usually formed with transition metals [3]. Metal hydrides are also defined as intermetallic compounds which are obtained by combining a stable-hydride forming element and an unstable hydride forming element. A very interesting property of metal hydrides is their ability to absorb and desorb hydrogen at a constant pressure [2]. They also offer the advantage of hydrogen storage under moderate temperatures while safely performing as high volume efficient storage [4]. The best known metal hydrides to absorb hydrogen are AB_5 type (for which the paradigm is $LaNi_5$) and the AB_2 type (like Mn_2Zn) hydrides. The AB_5 group has excellent hydrogenation performance at ambient temperatures but poor hydrogen capacity typically in the range of 1–1.5 wt.%. Metal hydrides based on magnesium (Mg and Mg_2Ni) have excellent hydrogen capacity (up to over 7 wt.%) but have unacceptably slow kinetics of hydrogenation and dehydrogenation, even after extensive activation at 673 K (400 °C) [5].

In practical applications, the rate of reaction in a metal hydride reactor is often limited by how quickly heat can be added to, or removed from, the hydride rather than the intrinsic kinetics of hydriding and dehydriding [2]. The performance of a metal hydride system depends on the properties of the selected metal hydride. Some of the desired properties are: high specific power output, compact in design, long life and low performance degradation and of course being economic. For a storage system, properties such as high hydrogen absorption capacity, high thermal conductivity, fast reaction kinetics, favorable equilibrium pressure, a simple activation process and minimum degradation after cyclic operation are desired as well [6].

An optimal hydride should have a higher chemical reaction rate than the rate by which the heat can be transported from the system. By deploying such a material, the dynamic of the storage system will be mainly dependent on the rate of heat transfer from the system. It is very important for the reaction to be repeatable in both directions (absorption and desorption of hydrogen) and the storage material should not fatigue during the process [7]. In this regard, uptake/release kinetics and retention of cycling capacity are two major study areas for material researchers [8]. Meanwhile, a general characteristics of the hydriding process is the sudden increase in the temperature of the absorbing bed when hydrogen is charged to the system. Different attempts; including insertion of aluminum foam, integration of copper wire net structure, packing in a multilayer waved sheet structure, micro encapsulated metal hydride compact, and compacting metal hydride powder with an expanded graphite were undertaken to enhance the heat conductivity of the hydrogen absorbing medium [9].

Improved heat conduction of hydrogen storing devices can be obtained through design parameters like heat exchanger, filters and geometrical distribution of the alloy inside the container. Although reactor geometry doesn't have any effect on hydride formation process but it influences the reaction speed [10]. Improved reactor configuration and heat exchanger design will elevate the storage capacity and hydrogen storage density and decrease refueling time [11]. It is to be mentioned that operating pressure and temperature are the governing factors in heat exchanger design [12]. In a metal hydride hydrogen storage system, a quasi-isothermal condition is desired in the bed. Thus, different reactors and heat exchangers were tested to acquire the effect of their design and configuration on hydriding process.

Different reactor and heat exchanger designs

As stated previously, there are many different parameters which effect the performance of a metal hydride reactor. A parameter with a crucial role in the reactor research is the configuration design. Even though there are different types of reactors proposed, the basic geometrical configurations of metal hydride reactors can be categorized as: tubular reactor, disc reactor, and tank or chamber reactor. Tubular reactors are the first type which were developed and investigated [13–16]. These reactors have good sealing and high bearing pressure. They also demonstrate effective heat and mass transfer if fabricated by rather thin tubes. Tubular reactors find their application in heat pumps and compressor systems while disc reactors are preferred for kinetic measurement and tank reactors are mostly implemented in storage systems. Fig. 1 illustrates the schematics of tubular reactor, annular disc reactor and tank reactor [17,18]. A compact configuration of tank reactor is micro channel reactor. This type of tank reactor occupies less space and offers quasi uniform temperature distribution inside the bed. A micro-channel reactor is shown in Fig. 2 [17].

Different parameters which affect the cooling and heating process in different hydride reactors have been studied through studies on heat and mass transfer [19–23], hydride properties [24,25] and system simulation [26–28]. Some of the proposed cooling and heating systems were fabricated and their performance was tested experimentally [14,29–34]. However, because of their application in hydrogen storage systems, only tank reactors are studied in this paper.

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