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A study on ideal distance between staggered metal hydride tanks in forced convection

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ABSTRACT

There are several critical parameters in specifying the satisfactory hydrogen flow in metal hydride tanks such dynamic factors in addition to the quantity contained in the tanks. Dynamic factors could be emphasized as ambient conditions and metal hydride properties. This work aims at investigating the effects of equilibrium pressure, ambient air temperature and velocity on ideal distance among metal hydride (MH) tanks used with the purpose of storing hydrogen in fuel cell applications as theoretically and numerically by using Autodesk CFD Simulation software. The metal hydride chosen for the present study is titled as LaNi5 in the literature. A new approach was utilized in the present study to describe the ideal distance among MH tanks using a novel approach in operating different conditions. Analyses implemented in this study are based on various ambient temperatures (i.e. 290K, 300K & 310K), Reynolds Numbers (i.e. 6000, 12,000 & 30,000) and equilibrium pressures (i.e. 60 kPa, 100 kPa & 120 kPa). As emphasized here, the ideal distance among MH tanks will be rather shortened while the Reynolds numbers increase during the operation. Moreover, it is noted here that the ideal distance will not be changed while the equilibrium pressure is in decrease and the ambient temperature is on the increase. Our findings indicate that distance among the MH tanks exists for maximum heat transfer. This finding could be utilized to maximize efficiency of the integrated metal-hydride-Fuel cell system without increasing additional costs.

Introduction

The diversity of availability and the renewability of hydrogen have opened the way for use in different engineering applications with the creation of an environmentally friendly [1]. The benefits of fuel cells should be reflected in hydrogen storage systems to ensure it works efficient way. Several techniques are utilized in the systems of hydrogen storage namely metal hydride, compression and liquefaction. The Hydrogen storage as a metal hydride is popular than other Hydrogen storage methods. The advantages of the above-mentioned techniques could be counted as reliability, safety and the capacity of hydrogen storage. The process of charging and discharging hydrogen within metal hydride cause two types of critical reactions namely exothermic and endothermic ones. These processes also require the control and enhancement of appearing thermal energy and efficiency. The

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effective utilization of hydrogen in metal hydride tanks could be realized in controlling thermal energy. It is therefore important to provide adequate hydrogen from tank to the system of a fuel cell with the purpose of enhancing the capability of the heat transfer. Inefficient thermal energy is considered as one of the most important disadvantages in the metal hydride and deal with the arrangement of metal hydride tanks due to the emphasis on the literature. Several models considering the power of mathematics have been developed to bring a proper solution in analyzing the properties of metal hydride tanks related to heat transfer. Afzal et al. [2] reviewed the existing literature a classification of heat transfer techniques and their relative effectiveness assessed with respect to system scale. They were observed that improvement of only thermal conductivity or heat transfer coefficient will not be able to improve system performance. An effective design should take into account the influence of both these parameters concurrently. Brikia et al. [3] were evaluated the experimental studies of the hydrogen absorption phenomenon in different reactors based on metal hydrides. The characteristics of the reaction kinetics in three different reactors using the same measurement conditions were compared. A numerical model describing the reaction kinetics of the H_2 absorption by $LaNi_5$ alloy validates the results were obtained. Of these results, it is found that the rate constant varies from one reactor to another. Mohammadshahi et al. [4] analyzed the mathematical models developed in previous studies that indicate a characteristic of variously applied equations, different assumptions and solution techniques. The performance of metal hydride concerning their effective factor, cooling system configurations and advanced reactor geometries are also evaluated by Mohammadshahi et al. Chibani and Bougriou [5] presented a numerical study of solid-state hydrogen storage and destocking in the Lanthanum Nickel ($LaNi_5H_2$) in a concentric triple-tube heat exchanger. Moreover, the influence of the thermal-reactor geometry for the storage and destocking hydrogen have been examined by changing the diameters of the heat exchanger. Andrea Mazzuccoa and Martin Dornheimb [6] examined advanced techniques relevant to the effective use of heat management systems integrated to metal hydride storage tanks. Moreover, they presented limitations and performance enhancements of developed solutions for heat management systems. Studies predicated upon alternative geometrical solutions and/or operation techniques are considered, what's more, their related preferences are clarified. . Improving heat transfer during hydrogen take-up and release has observed to be fundamental to enhance storage limits and limit time necessities. Shahin Shafieea and Mary Helen McCay [7] focus on the issue of thermal control while concentrating on reactor and heat exchanger setups. In the study, alternative reactors and heat exchangers for metal hydride storage systems are investigated, classified and compared. Bhogilla [8] designed metal hydride tank for stationary application and developed 3D numerical model. Veerraju and RamGopa [9] presented time-dependent heat and mass transfer model to anticipate the usability of elliptical tube metal hydride reactors and obtained ideal solutions for the elliptical hydride tube bank reactors. Bhouria and Goyette [10] investigated numerically the enhancement of the hydrogen by maximizing the heat transfer rate charging in a multi-tubular metal hydride reactor with longitudinal fins. optimized the design parameters on the hydrogen charge capacity is defined. Johnson et al. [11] designed, fabricated, and tested a prototype metal hydride tank which was optimized by maximizing the effectiveness of heat transfer properties. Raju and Kumar [12] investigated optimization of heat exchanger design with computational fluid dynamics and different types of heat exchanger designs have been examined in terms of geometric parameters. MacDonald and Rowe [13] have analyzed models to increase heat the effects of external convection resistance on thermal behavior in a tank. Jemni and Nasrallah [14] proposed an analytical model for time-dependent heat and mass transfer in the metal-hydride tank. Aldas et al. [15] analyzed thermal behavior in the metal hydride reactor. Bao et al. [16,17] and Cho et al. [18] modelled metal hydride storage mechanism according to the design parameters and various operating conditions. Minko et al. [19,20] studied heat and mass transfer in metal hydride as a porous medium. Ma et al. [21] derived heat transfer equations of metal hydride tank according to different fin properties. Nakano et al. [22] designed and fabricated a novel metal-hydride tank with coiled heat exchanger. Dhaou et al. [23] studied and compared different metal hydride tank with spiral heat exchangers according to heat transfer efficiencies Sekhar et al. [24] modelled heat-and-mass transfer in four different metal-hydride tanks for the comparison of hydrogen charging.many studies are also studied on integrated fuel cell-metal hydride system. Macdonald and Rowe [25] and Førde et al. [26] investigated thermal characteristic of integrated system. Rizzi et al. [27] constructed power system driven by the fuel cell and six metal hydride tanks and tested in different working conditions. A mathematical model was proposed for thermal management of an integrated system by Tetuko et al. [28]. Jiang et al. [29] investigated the dynamic thermal behavior of integrated metal-hydride and fuel cell system according to validated models as experimental Hilali [30] emphasized that the sequence of the tank was effective on hydrogen discharge capacity according to different thermal conditions and suggested to optimize according to hydrogen flow rate. To find an ideal arrangement, there are some correlations which they give an ideal distance for maximum heat transfer and ideal volume, in the literature [31].

Finally, this study aims to contribute to literature aspects of arrangements model of metal-hydride tank banks in different ambition conditions. Also, numerical simulations are performed in Autodesk CFD Simulation for of this model. In below sections, step-by-step formulation of the mathematical model and results were presented.

Mathematical modeling

Fig. 1 shows the schematics of the arrangement of metal hydride tanks considered in this work. $LaNi_5$ (AB_5) was selected as metal-hydride alloy because it meets low desorption pressure (~4 bar) at ambient temperature. Moreover, Reaction kinetics and thermophysical properties of $LaNi_5$ are easily found in relevant studies. For the modeling, firstly, the relevant

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