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Harnessing Microwave and Heat Exchanger for Enhanced Hydrogen Desorption in MgH2 Hydride Storage System

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1. ABSTRACT

The desorption process in hydrogen storage, particularly in metal hydrides, poses challenges regarding efficiency and desorption speed. This study explores the utilization of microwave energy to accelerate the desorption process, thereby yielding hydrogen as a feasible option for energy storage. Numerical simulations were conducted using COMSOL Multiphysics software and the finite element method (FEM) in this research. The analysis compares two heat application methods for metal hydrides: conventional heat exchangers and concentrated microwave heating systems. The objective is to assess and contrast the effectiveness of various hydrogen release techniques in minimizing desorption time. Results indicate that employing microwave energy at 100 W and 2.45 GHz significantly reduces desorption time from 105 to 39 minutes, compared to applying 100 W/m^2 of heat via a heat exchanger. This reduction addresses the challenge of hydrogen release, marking a substantial advancement in energy storage technology.

2. INTRODUCTION

Metal hydrides, particularly magnesium hydrides, have attracted significant attention as potential materials for hydrogen storage. Despite their advantageous properties, such as capacity and relative abundance, challenges persist in efficiently releasing hydrogen from these compounds. While magnesium hydride offers advantages in terms of cost compared to certain hybrid hydrides, enhancing the speed and efficiency of hydrogen release remains crucial for realizing hydrogen's potential as a viable energy source, especially in mobile applications and vehicles [1]. Scientists have explored various energy application methods, including heat exchangers thermochemical materials (TCM), and phase change materials (PCM) to improve the desorption process and elevate the temperature of the hydride to facilitate hydrogen release [2]. However, achieving rapid and efficient hydrogen release requires innovative approaches. Microwave energy has emerged as a profitable solution due to its versatility and efficiency in accelerating the desorption process.

This research focuses on harnessing the unique capabilities of microwave energy to accelerate hydrogen release from magnesium-hydride-based metal hydrides. While microwave energy has been utilized in various processes, its application in metal hydride hydrogen release presents new challenges due to the need for a comprehensive understanding of hydrogen release mechanisms and material structures. The study aims to investigate the effectiveness of microwave energy at different stages of the hydrogen release process to enhance efficiency and speed compared to conventional thermal methods. By examining the effectiveness of microwave energy in expediting hydrogen release from magnesium hydride, this research aims to develop practical methods for accelerating hydrogen release from metal hydride-based storage systems.

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3. METHDOLOGY

In this study, our main focus lies in the numerical analysis of the hydrogen desorption process within a tank containing magnesium hydride. Our approach involves utilizing both conventional heat exchangers and microwave systems to enhance the desorption process. The tank's design geometry, featuring a diameter of 30 mm and a length of 100 mm, was optimized to integrate the hydrogen storage system as illustrated in Figure 1.

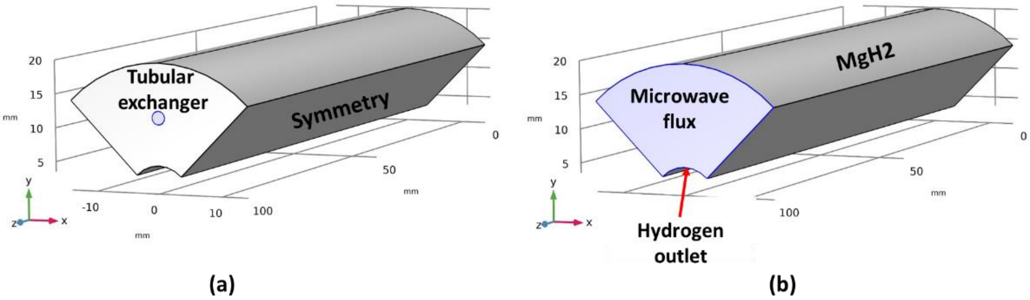

Fig. 1 Schematic Representation of Magnesium Hydride Tank (a) Enhanced by Heat Exchanger, (b) Integrated with Microwave Heating System

The boundary conditions depicted in Figure 1 provide a comprehensive framework for our simulation. Initially, the tank is filled with hydrogen gas, operating under atmospheric pressure conditions. Given the endothermic nature of the hydrogen removal process, supplying additional heat becomes crucial to accelerate desorption process and release of hydrogen. This is achieved through the utilization of both heat exchangers and microwaves. Setting the initial temperature at 553 K, which marks the threshold temperature for hydrogen discharge initiation, enables the continuation of the process with the application of external heat. Throughout the simulation, various parameters were investigated, with particular emphasis on crucial factors such as the gas diffusion rate, system pressure, and temperature distribution within the porous medium. The formula for calculating the generated heat by microwave radiation is presented as Eq.1.

$$Q_{MW} = \pi f \varepsilon_0 \varepsilon_r'' |\vec{E}| \quad (1)$$

The formula for microwave-generated heat (Q_{MW}) involves key components: f (frequency), ε_0 (permittivity of free space), ε_r'' (relative permittivity), and $|\vec{E}|$ (electric field intensity).

4. RESULTS

The main focus of our research was to compare the effectiveness of conventional heat exchangers and microwave technology in expediting the removal of hydrogen. Our study was evaluated with Lutz et al.[3], which utilized thermochemical (TCM) to initiate hydrogen removal and optimize energy consumption. The results, illustrated in Figure 2 and obtained through simulations, revealed that using a conventional heat exchanger reduced the removal time by approximately 105 minutes compared to thermochemical materials. Conversely, microwaves dramatically accelerated the removal process, reducing the time to just 39 minutes. This significant time difference was attributed to the swift temperature increase in the metal hydride induced by microwave radiation, compensating for the decrease in removal quality observed over time and compared with the Lutz et al. experiment.

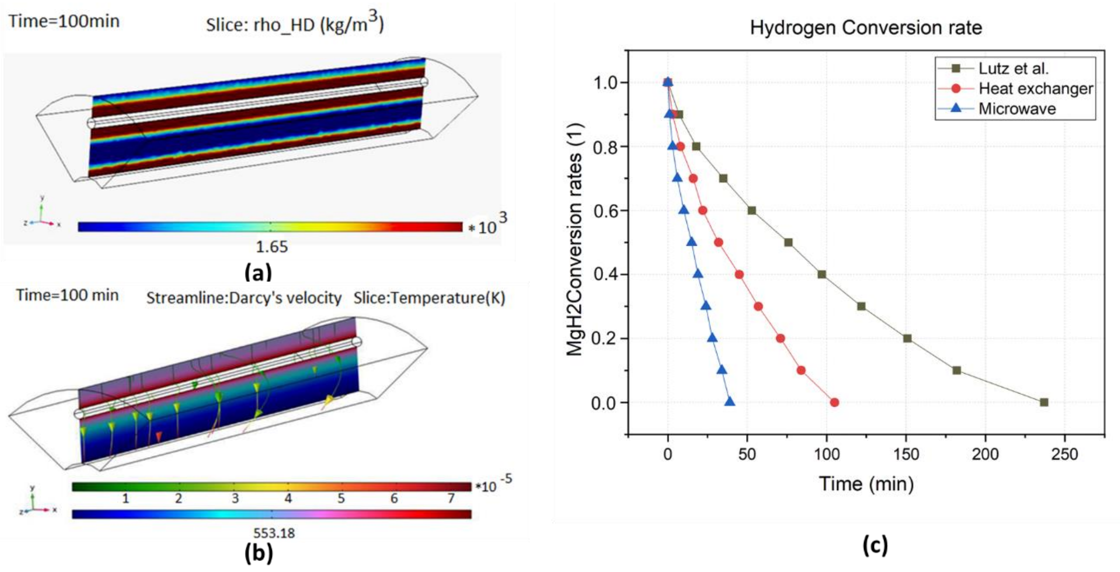

Fig. 2 Metal hydride conversion rate (a) hydrogen distribution (b) Darcy velocity field, and temperature (c) Comparing desorption time.

Moreover, microwave assistance significantly accelerated the transition from the beta phase to the alpha phase during the removal process, highlighting its superior efficiency compared to other methods. Transitioning from the beta phase to the alpha phase presents a challenge due to the higher release capability in the alpha phase. However, the application of additional heat, along with microwaves, weakened chemical bonds in the beta phase, facilitating hydrogen separation during the transition to the alpha phase. This significantly eased the removal process compared to situations where no external energy source was applied. Microwaves have a unique ability to penetrate deeply into the metal hydride system, resulting in a more widespread distribution of energy compared to other methods. Consequently, microwaves effectively raise the metal hydride's temperature, accelerating the breaking of bonds between hydrogen molecules and the magnesium.

5. CONCLUSIONS

Microwave technology emerges as vastly superior to conventional methods for hydrogen release, accelerating the desorption process to 39 minutes from 105 minutes with heat exchangers. Moreover, microwaves enhance the transition from the beta to alpha phase, maximizing efficiency. Their deep penetration and uniform energy distribution establish microwaves as the premier option for boosting hydrogen release.

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