Investigation of Metal Hydride based Thermochemical Energy Storage System for High Temperature Applications

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Abstract

Thermal energy storage is considered as one of the viable solutions for intermittency and diurnal variation of solar energy. Utilization of thermal energy storage helps to improve the capacity utilization factor and dispatchability of solar thermal power plants. Thermochemical energy storage has higher energy storage capacity and lower heat losses, implying higher energy storage efficiency as compared to sensible and latent heat storage. The work focuses on investigation of a metal hydride based thermochemical energy storage system for high temperature (500°C) applications. As metal hydride based thermochemical energy storage has high thermal stability, longer cyclic life, and better reversibility as compared to other thermochemical energy storage systems. Therefore, it can be an appropriate solution for high temperature energy storage applications.

A dual metal hydride system uses two metal hydrides, namely high temperature and low temperature metal hydride. Energy storage takes place in high temperature metal hydride. In this work, $NaMgH_2F$ is used as energy storage media, while Mg_2NiH_4 is used as low temperature metal hydride for hydrogen storage.

An experimental test facility is developed to characterize the metal hydride sample up to an operating temperature of 300°C. Physical characterization of the Magnesium Nickel (Mg-Ni) alloy sample is performed using X-ray diffraction (XRD) and scanning electron microscope (SEM) analysis, followed by the development of pressure composition isotherm of Mg-Ni alloy at 250°C, 275°C, and 300°C. The Mg-Ni alloy sample has shown relatively lower plateau pressure at the above mentioned temperature as compared to other complex metal hydrides. The maximum hydrogen storage density of 3.31 wt% is observed, which is approximately 90% of the theoretical hydrogen storage density reported in the literature.

The numerical study performed in this work investigates heat transfer and performance analysis, such as energy absorption, desorption, and storage efficiency, with variations in geometries and heat transfer flow arrangements. The identification of adequate heat transfer fluid tubes and the effect of aspect ratio (diameter to height ratio) on the energy storage and heat transfer phenomenon in Mg_2NiH_4 is performed. The outcome of this analysis concluded that the reactor geometry with less aspect ratio has shown better heat transfer in the cross sectional domain. It also concluded that heat transfer fluid tubes embedded in metal

hydride reactor needs nearly 18% of the metal hydride cross sectional area (area cross section ratio) for effective heat exchange between the metal hydride and heat transfer fluid. The adequate heat transfer fluid tubes are identified in this analysis for aspect ratios 0.5, 1, and 2 are 32, 48, and 54, respectively. A maximum and minimum energy storage efficiency of 93.27% and 91% is observed for aspect ratios 2 and 0.5, respectively.

The analysis performed on $NaMgH_2F$ investigated the effect of variation of initial metal hydride reactor temperature and different heat transfer fluid flow configurations on heat transfer and performance characteristics of metal hydride system. The heat transfer fluid flow configuration 1 has axial heat transfer fluid tubes distributed radially in the cross section, while configuration 2 has a circumferential heat transfer fluid arrangement along with axial heat transfer fluid tubes distributed radially in the cross section. The study concluded that the higher initial temperature of metal hydride reactor results in higher thermal energy storage efficiency. The metal hydride reactor with circumferential heat transfer fluid flow arrangement (configuration 2) has shown better heat transfer characteristics. A maximum thermal energy storage efficiency of 96.4% is obtained for the metal hydride reactor at 823 K with circumferential heat transfer fluid flow arrangement.

The dual metal hydride bed system is studied for heat transfer and performance characteristics with different thermal conductivities of energy storage media. The energy storage efficiency of the dual metal hydride system improved marginally from 94.44% to 95.11% when the thermal conductivity of high temperature metal hydride is increased from 0.5 W/(m.K) to 4 W/(m.K). In addition, the single metal hydride system and dual metal hydride bed system are compared for the thermal and energy storage characteristics. The maximum energy storage efficiency is found to be higher for dual metal hydride systems as compared to single metal hydride systems. The maximum average temperature variation of energy storage media was 33 K and 4 K for single and dual metal hydride based thermal energy storage systems, respectively.

In summary, the study presents a detailed heat transfer and performance analysis of a dual metal hydride bed system. The study compares the heat transfer and performance characteristics of single and dual metal hydride bed systems. The outcomes of the analysis will facilitate the designing of a metal hydride based thermal energy storage system with effective heat transfer and enhanced energy storage characteristics for high temperature applications.