Journal of Energy Storage 14 (2017) 203–210

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Design of a AB_2-metal hydride cylindrical tank for renewable energy storage

Satya Sekhar Bhogilla

Faculty of Mechanical Engineering, Indian Institute of Information Technology Design and Manufacturing Kurnool, India

ARTICLE INFO

Article history:
Received 24 July 2017
Received in revised form 29 September 2017
Accepted 18 October 2017
Available online xxx

Keywords:
Metal hydrides
Hydrogen storage
Heat and mass transfer
Thermal model

ABSTRACT

Metal hydrides have the ability to reversibly absorb and desorb relatively large amounts of hydrogen at a certain temperature and pressure. The absorption of hydrogen in metal hydrides is an exothermic reaction, therefore, the generated heat has to be removed effectively in order to achieve the desired charging rate.A 3D numerical model has been developed for predicting the hydrogen absorption process performance of cylindrical metal hydride tank (MHT) filled with $Ti_{0.98}Zr_{0.02}V_{0.43}Fe_{0.09}Cr_{0.05}Mn_{1.5}$ hydrogen storage material. Heat exchange arrangement considered between the MHT and the heat transfer fluid for cooling is helical coil internal heat exchanger in the powdered metal hydride bed. The performance of the MHT is analyzed based on the numerical simulation. The effect of heat transfer coefficient on characteristics of the helical coil reactor is also analyzed. The numerically predicted results are validated with the experimental data available in the literature. The predicted MHT hydrogen storage capacity is about 1.8 wt% at the operating conditions of 20 bar supply pressure and heat transfer fluid temperature of 293 K.

1. Introduction

In recent years, the climate is changing rapidly due to increase in pollution level that causes heavy rains in some areas and severe draught in other areas. At present the entire humanity is looking for clean and renewable energy. Solar and wind energy are the main sources of renewable energy. But these two sources can't provide continuous power. Wind energy is available when the wind is blowing and solar energy is available when the sun is shining. Due to this both solar and wind energy resources can't produce energy round the clock, which is a major drawback. The daily operation of the electric grid is very challenging with the integration of intermittent renewable power to the electric grid. The intermittent renewable power varies over multiple time horizons so that the grid has to adjust instantaneously. Development of appropriate energy storage technology is required to utilize renewable energy effectively. In the last two decades, the prime focus of several researchers is on storing renewable energy whenever it exceeds the demand and supplying the power when demand is higher than energy generation from renewable energy [1–6]. Many researchers found several options for storing renewable energy. The hydrogen based renewable energy storage system is one of the best options to store renewable energy. Hydrogen has the highest gravimetric energy density than any other fuels and it has numerous attractive characteristics as a key energy carrier in the near future. In hydrogen based energy storage, the energy loss due to long term storage is very small compared to secondary batteries [7]. Hydrogen can be produced from water electrolyzer (WE) by supplying excess power from the power grid. This produced hydrogen from WE will be stored in hydrogen storage tank. The stored hydrogen from the tank will be supplied to fuel cell (FC) to compensate the power deficit (renewable energy supply is less than power grid demand). The FC converts the hydrogen energy into electricity and heat. There are two types of WE's mostly used in the renewable energy based hydrogen production plants viz, alkaline WE and Polymer electrolyte membrane WE (PEM). PEM type WE has simple process layout and no need to circulate the liquid electrolyte compared to alkaline WE. This advantage enables PEM type WE to respond very fast to load variations and easy start-up. Hence, PEM type WE's are suitable to integrate with intermittent renewable power sources [8–10].

Many technologies are available to store hydrogen gas. Based on the type of application, storage time, energy density, capital, maintenance and operating cost, the storage system can be

E-mail addresses: satyasekhar@iiitk.ac.in, satyasekhar6@gmail.com (S.S. Bhogilla).

https://doi.org/10.1016/j.est.2017.10.012

Nomenclature

C_a Reaction rate constant, s^{-1}
C_p Specific heat, $J\,kg^{-1}\,K^{-1}$
E_a Activation energy, $J\,(mol\,H_2)^{-1}$
ΔH Enthalpy of reaction, $J\,(mol\,H_2)^{-1}$
ΔS Entropy of reaction, $J\,(mol\,H_2)^{-1}\,K^{-1}$
K Permeability, m^2
k Thermal conductivity $W\,m^{-1}\,K^{-1}$
M_g Molecular weight of hydrogen, $kg\,kmol^{-1}$
P Pressure, bar
Q Volumetric heat source term, $W\,m^{-3}$
r_o Outer radius of the reactor, m
R_u Universal gas constant, $J\,mol^{-1}\,K^{-1}$
t Time, s
T Temperature, K
U Over all heat transfer coefficient, $W\,m^{-2}\,K^{-1}$
u Velocity, m/s
V Volume, m^3
X Hydrogen concentration, H/M ratio
ε Porosity
β Hysteresis factor
φ, φ_o Slope factors
μ_g Dynamic viscosity, $kg\,m^{-1}\,s^{-1}$
ρ Density, $kg\,m^{-3}$

Subscripts
e Effective
eq Equilibrium
f Final
g Gas
i Initial
m Metal
s Supply
ss Saturated solid

selected. For example, weight of the storage system is not a crucial factor for stationary applications. Storing of hydrogen in compressed form is the simplest method. In this method, hydrogen is compressed by using a compressor and stored in thick steel cylinders or composite cylinders. The second option is liquid hydrogen storage system. In this method, hydrogen liquefies at its liquefaction temperature of 20 K so that the storage system needs highly sophisticated tanks to insulate the heat transfer from atmosphere to tank. The latter option has higher energy density than the previous method. However these two methods require additional energy to compress (15% of hydrogen heating value at 200 bar) or liquefy hydrogen (28% of hydrogen heating value), and safety is a major concern [11,12]. The third method is the physical-chemical method in which hydrogen is stored in some suitable storage materials ex. activated carbon, zeolites, metal hydries and metal organic frameworks by absorption/adsorption process. Many materials were developed by several researchers. Metal organic frameworks and activated carbon adsorb hydrogen at very low temperatures in the range of −208 to −195 °C, which means to cool the storage medium, additional energy is required. Zeolites adsorb hydrogen in the pressure range of 25–100 bar and temperature range of 20–200 °C. In organic hydrides, hydrogenation/dehydrogenation process takes at high temperatures (200–400 °C) and thus requires the large amount of heat input [13,14]. Metal hydrides are very promising materials for hydrogen storage because hydrogen absorption and desorption can be done at ambient temperatures. Though the volumetric hydrogen storage capacity of metal hydrides is high, they have low gravimetric hydrogen storage capacity. But this is not a drawback for stationary applications when compared to mobile applications. Metal hydrides absorb hydrogen by releasing exothermic heat and for desorbing hydrogen, the endothermic heat should be supplied. This exothermic and endothermic heat can be useful in other applications like heating and air conditioning applications. Thus, heat management in the storage tank is very crucial because it affects the hydrogen absorption/desorption rate [15,16].

Fig. 1 shows the conceptual overview of the hydrogen based renewable energy storage system. The excess power from the power grid will be supplied to WE and it produces hydrogen. This produced hydrogen will be stored in hydrogen storage system. When there is power deficit in the power grid, the stored hydrogen will be supplied to FC. The FC converts hydrogen into electricity and heat. The storage system of hydrogen is one of the crucial components of the total system. The purpose of metal hydride tank (MHT) is to absorb and desorbs hydrogen for storage and simultaneously utilize reaction heat for air conditioning.

Tange et al. [17] conducted several experiments and presented detailed results for hydrogen storage tanks with metal hydrides

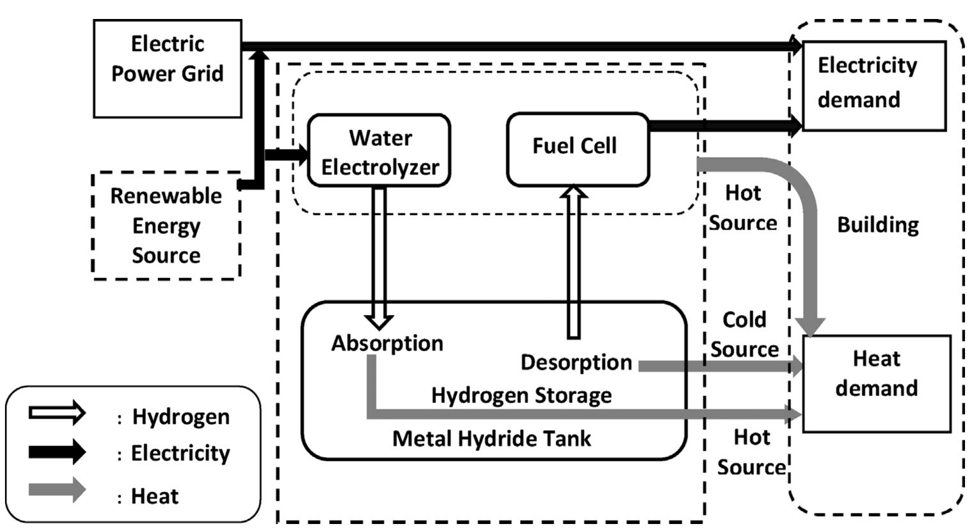

Fig. 1. Shows the conceptual overview of hydrogen based renewable energy storage system.