National Institute of Technology Rourkela

Synopsis Seminar

Seminar Title	: Design and Optimization of Solid-State Hydrogen Storage Reactors For Thermal Applications
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Venue	: ME Seminar Hall [ME001]
Date and Time	: 15 May 2025 (04.00 pm)

Abstract

: An appropriate thermal management system design in the reaction bed is undoubtedly needed to achieve the optimum thermal performance of the metal hydride-based hydrogen storage reactor. The developed 3D thermal model examined the hydrogen sorption performance of diverse heat exchanger configurations, namely, (i) capillary bundled reactor, (ii) tubular bundled reactor, and (iii) helical coiled reactor. The performance of these heat exchanger configurations of identical reactor size was compared with an embedded cooling tube bed comprising 2.75 kg $LmNi_{4.91}Sn_{0.15}$ under homogeneous and pragmatic operating conditions. Helically coiled reactors exhibit faster absorption and desorption than embedded cooling tubes with a comparatively better weight ratio. It is observed that coils of smaller diameter (4 spiral tubes of 3.175 mm diameter) with a pitch of 8 mm can produce a moderate 420&ndash500 W/kg_h of thermal power under 320 s. From the comparative analysis, it is concluded that HCR layouts are inherently suited to hydride reactor beds as they confront the reactor's maximum pocket width or characteristic length most closely and provide fabrication convenience and a high heat transfer coefficient. Furthermore, the unified comparison of ECT and HCR reactors under identical volume and operating conditions indicates that the latter exhibits significantly superior absorption performance and an exceptional weight ratio when fabricated.

Following the most favorable heat exchanger design selection, research focuses on optimizing the weight and thermal performance of $LaNi_5$-holding helically coiled hydride reactors employing combined response surface methodology, computational modeling, and a desirability approach. The structural geometric design optimization factors include the diameter of the helical tubes and shell, the number of helical tubes, the pitch, and the distance between two adjacent helical tubes. Responses comprise a dimensionless characteristic response&ndashweight ratio (static performance) and 90% absorption time with maximal heat extraction rate (thermal performance). The quadratic regression model outperformed the linear regression models in terms of accuracy and reliability, effectively reducing the number of computational runs by 83% compared to the standard parametric study-based technique. Combinatorially assessing the weight ratio and thermal power to be set to the maximum at the quickest absorption time resulted in selecting the best helical reactor design - 5 in shell diameter, 0.125 in pipe diameter, with a pitch of 6.5 mm, 4 coils, and coil positioning being configuration 2.

The first of its kind, a four-helical copper tube-structured AB5-based hydrogen storage reactor, is fabricated based on the prior multi-objective optimization method. The reactor employed a 4 x 1.6 mm copper tube and recorded a weight ratio of 0.65. This study advances a pioneering thermal augmentation strategy, uniquely incorporating 3% pure micro-copper powder (5 &mum size) into the alloy bed. It enhanced thermal power by 43&ndash58%, reduced absorption time by 27&ndash32%, and enhanced heat extraction efficiency by 5&ndash6% across all experimental cases. Heat utilization efficiency increased by 11.04% through copper powder and inline filter removal. The integration of a 600 W PEMFC (G-HFCS-600W24V) revealed that the non-preheated (no inline filters case) resulted in an 11.6% increase in daily cycles and a 27.7% enhancement in net energy gain, leading to an 11.3% annual increase in usable energy. The levelized energy cost declined by 9.5% ($1.62/kWh compared to $1.79/kWh). The findings demonstrate that micro-copper powder and waste heat recovery effectively optimize hydrogen release, improving energy efficiency for off-grid power backup applications.

A dual-helical coiled reactor was fabricated using the dual-objective optimization result to reduce absorption time and enhance thermal power through imperative design modifications. The design modifications include silver electroplating to the inner surface of the shell, integrating aluminium 6081 support rods for better helical coil integrity, and reducing shell and tube thickness to improve the weight ratio. The fabricated reactor yielded a maximum weight ratio of 1.62 due to filling 5.6 kg of La-based alloy. The reactor is filled with 5 kg of La0.91Ce0.09Ni3.5Fe1.5 material. The reactor is fabricated at an expense of $140, and the silver electroplating incurred $66. The levelized cost of hydrogen storage for the dual-helical reactor is estimated at $3701.35/$kg_H$ for the operating condition of 20 bar, 298 K, and 3 lpm. The fabricated dual-helical reactor can store about 65-70 g of hydrogen when operated at 15-20 bar pressures (298 K and 3 lpm). The reactor yielded thermal power and a specific heat extraction rate of 180.39 W/kg_h and 2239.51 W/kg_h mm^3. The designed dual-oppositely placed helical copper tube layout exhibited heat exchange effectiveness of 0.95&ndash0.97 and 98&ndash99% reversibility in desorbing the absorbed quantity of hydrogen. The absorption studies revealed that the reactor achieved gravimetric and volumetric storage densities of 0.83% and 32.28 kg_H/m^3, respectively, the highest reported in hydride-based hydrogen storage reactors.