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Experimentally tuned dual stage hydrogen compressor for improved compression ratio

Md Mainul Hossain Bhuiya [a,1], Chi Young Lee [a,2], Taeseon Hwang [c], Sirajum Munira [a,3], Ryan Hopkins [a], Hyungkee Yoon [c], Sang Heup Park [d], Kwang J. Kim [b,*]

[a] Mechanical Engineering Department, University of Nevada, Reno (UNR), 1664 N Virginia Street, Reno, NV 89557, United States

[b] Mechanical Engineering Department, University of Nevada, Las Vegas (UNLV), 4505 Maryland Parkway, Las Vegas, NV 89154-4027, United States

[c] Solar/Geo Thermal Research Laboratory, Korea Institute of Energy Research (KIER), 152 Gajeong-ro, Yuseong-gu, Daejeon 305-343, Republic of Korea

[d] Division of Mechanical and Automotive Engineering, College of Engineering, Kongju National University, 275 Budae-dong, Cheonan 330-717, Republic of Korea

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ABSTRACT

An experiment-driven design procedure for optimizing the combination of stages of a dual stage hydrogen compressor with enhanced compression ratio is presented herein. Three different combinations of reactors were used using $LaNi_5$, $Ca_{0.6}Mm_{0.4}Ni_5$ and $Ca_{0.2}Mm_{0.8}Ni_5$ as hydrogen storage materials. Compression ratios were found to be similar for low supply pressure conditions, which improved significantly for high supply pressure conditions in single stage experiments. A dual stage compressor system with $LaNi_5$ in first stage and $Ca_{0.2}Mm_{0.8}Ni_5$ in the second stage was proposed based on single stage results, which was found to be very effective for enhancing compression ratio. Results show that 53% higher compression ratio can be attained by selecting appropriate storage materials for stages, compared to $LaNi_5$ based economic dual stage system.

* *Corresponding author*. Tel.: +1 702 774 1419 (office).
E-mail addresses: bhuiyam@unlv.nevada.edu (M.M.H. Bhuiya), whitelcy270@gmail.coms, chiyounglee@kaeri.re.kr (C.Y. Lee), Taeseon.hwang@unlv.edu (T. Hwang), sirajum.munira@utexas.edu (S. Munira), hopkinsawai@yahoo.com (R. Hopkins), hgyoon@kier.re.kr (H. Yoon), weldpark@kongju.ac.kr (S.H. Park), kwang.kim@unlv.edu (K.J. Kim).
[1] University of Nevada, Las Vegas (UNLV), 4505 Maryland Parkway, Las Vegas, NV 89154-4027, United States.
[2] LWR (Light Water Reactor) Fuel Technology Development Division, KAERI (Korea Atomic Energy Research Institute), Korea.
[3] Globalfoundries, 400 Stone Break Road Extension, Malta, NY 12020, United States.
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Introduction

Hydrogen is one of the most anticipated renewable energy sources for the future. Due to the unique ability of storing hydrogen at room temperature within the lattice and with density greater than the liquid hydrogen, metal hydrides (MH) have long been established as excellent mediums for hydrogen storage [1–7]. While the kinetics of hydrogen absorption and desorption remain complex and are greatly influenced by a number of thermo-physical properties of the storage material, the processes for hydrogen storage and compression can be explained by simpler physicochemical process that takes place during the operation. Hydrogen is first absorbed into the porous metallic pellets stacked inside the reactor at low supply pressure and at low temperature. It remains in the hydride structure until the system is exposed to an elevated temperature or vacuum, which cause the stored hydrogen to exit the hydride lattice. If the temperature rise is sufficient and the system gains the activation energy to initiate desorption reaction, hydrogen exits the metal hydride at pressures that range from approximately 3–10 times [8–22] the original supply pressure of a single stage compressor. Multistage metal hydride hydrogen compressors use a combination of metal hydrides at different stages to enhance the final compression ratio by maximizing absorption from the desorbed hydrogen of prior stages. Recently a dual stage hydrogen compressor [11,23,24] has been proposed that utilized both AB_5 and AB_2 metal hydrides to compress hydrogen from 4 MPa to a final storage pressure of 45 MPa using hot water as the working fluid. A final compression ratio of approximately 11 was obtained by this dual stage system.

The working principle of a dual stage compressor can be described using the simplified illustration of such system shown in Fig. 1(A). The single stage compressor is also shown in the inset of the figure. During the operation of a dual stage compressor, initially all the valves remain closed. When valve-1 is opened to expose the storage material to low pressure hydrogen at a lower temperature, hydrogen is absorbed and hydride is formed by an exothermic reaction inside the reactor 1. When saturation is reached, valve-1 is closed and subsequently reactor 1 is heated until the steady state H_2 pressure is built inside. In the meantime reactor 2 is being cooled to prepare it for absorption process. Opening valve-2 at this point allows the desorbed hydrogen from the first stage, to be absorbed in the second. Valve-2 is then closed after saturation is reached and subsequently reactor 2 is being heated to initiate final desorption process. Finally, valve 3 is opened to obtain high pressure H_2. This working principle corresponds to the system temperature and desorption pressure as shown in Fig. 1(B) [23]. State A in the figure represents a lower absorption temperature at which $LaNi_5$ reactor absorbs and stores hydrogen. As the temperature is increased after saturation, system pressure gradually increases since hydrogen desorbs from the storage material. At State B, desorption pressure reaches the peak and then the high pressure hydrogen is allowed to flow into the second stage for absorption representing state C. At this point there is a significant decrease in the system pressure since there presurize hydrogen starts to get absorbed in the second stage storage material and also occupy the plumbing volume between stages. Finally, the second stage stored hydrogen is desorbed by application of heat and the system eventually reaches a final state D where the final pressure is significantly above the initial absorption pressure at state A. The process as described can be continued for subsequent cycles as required. The single stage compressor works in the same principle except the fact that there is no second reactor and the process is performed for the first stage only.

The materials selected for storage of hydrogen at different stages of reactor comprises of three variation of AB_5 type nickel based storage system. They are: $LaNi_5$, $Ca_{0.6}Mm_{0.4}Ni_5$ and $Ca_{0.2}Mm_{0.8}Ni_5$. As shown in Fig. 2, AB_5 type (such as Ni based materials) is comparatively better option because of the fact that they operate at moderate temperature, which is within the range of waste heat temperature. Also, from the economic aspect of the project and availability of the materials, nickel based AB_5 type was the best option that was considered for the project. Even though AB_2 (such as Ti based materials) types can yield even higher compression ratio, they

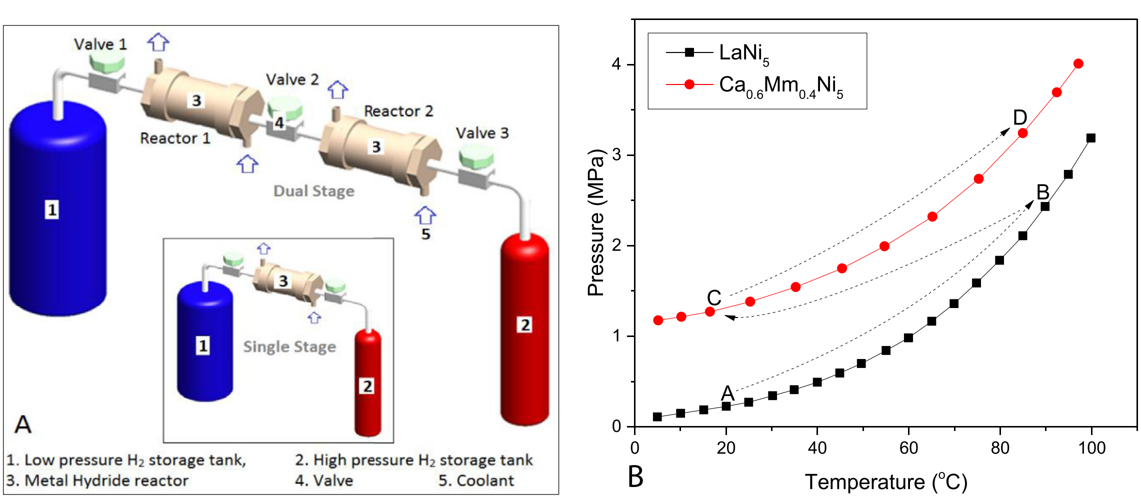

Fig. 1 – (A) Schematic diagram and (B) working principle [23,25] based on pressure–temperature data of multi stage metal hydride hydrogen compression system.