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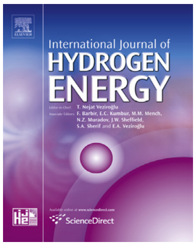

Analysis of crossed van’t Hoff metal hydride based heat pump

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ABSTRACT

In this paper, the operating feasibility of a single-stage metal based hydride heat pump (SS-MHHP) working on the principle of crossed van’t Hoff line concept is presented. The performance of the system is predicted by solving the unsteady, two-dimensional mathematical model in an annular cylindrical configuration employing two different hydride alloy pairs, namely, $V_{0.846}Ti_{0.104}Fe_{0.05}/Fe_{0.9}Mn_{0.1}Ti$ and $V_{0.855}Ti_{0.095}Fe_{0.05}/MmNi_{4.7}Al_{0.3}$ (regeneration alloy/refrigeration alloy). The influences of heat source (T_H) and refrigeration (T_C) temperatures on the amount of hydrogen transferred between the paired reactors, coefficient of performance (COP) and specific cooling power (SCP) of the crossed van’t Hoff SS-MHHP system are studied. Within the selected ranges of operating temperatures, the COP of the crossed van’t Hoff SS-MHHP is about 60% higher than the conventional single-stage MHHP. The optimum operating temperatures of $V_{0.846}Ti_{0.104}Fe_{0.05}/Fe_{0.9}Mn_{0.1}Ti$ and $V_{0.855}Ti_{0.095}Fe_{0.05}/MmNi_{4.7}Al_{0.3}$ combinations are found to be 373/303/291 K and 400/303/283 K (heat source/heat sink/refrigeration temperatures), respectively. At the optimum operating temperatures, the COP and SCP of the $V_{0.846}Ti_{0.104}Fe_{0.05}/Fe_{0.9}Mn_{0.1}Ti$ and $V_{0.855}Ti_{0.095}Fe_{0.05}/MmNi_{4.7}Al_{0.3}$ combinations are 0.89 and 30.8 W/kg of total mass and 0.86 and 30.3 W/kg of total mass, respectively.

1. Introduction

Over the last two decades, the applications of metal hydrides have been explored in various heating and cooling systems [1]. Of particular current interests are metal hydride based heat pumps and refrigeration systems, which do not have any mechanical moving parts, utilize low grade heat and compete to be an environmental friendly. Past two decades many investigators have studied the performance of single-stage metal hydride based heat pumps (SS-MHHP) using numerical models [2–4] and experiments investigations [5–7]. Libowitz et al. [8] introduced the concept of cross van’t Hoff MHHP. The consequence of crossed van’t Hoff SS-MHHP is to utilize the enthalpy formation of the refrigeration alloy for driving system. They reported four possible hydride alloy pairs for cross van’t Hoff MHHP. Among those, $V_{0.855}Ti_{0.095}Fe_{0.05}/LaNi_5$ yielded the maximum theoretical COP (including sensible heating recovery) of 0.83 (conventional COP = 0.64) in the selected operating temperature ranges of 135–175 °C/25 °C/5 °C ($T_H/T_M/T_C$). However, their study was limited to only thermodynamic calculations and they have not reported the influences of various operating temperatures on the performances of the system.

Recently, the author’s research group at IIT Guwahati has developed several thermal models for predicting the performances of the SS-MHHP and double – stage MHHP [9,10]. In the present paper, the authors extend their earlier developed mathematical model of SS-MHHP for investigating the

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influences of operating temperatures on the performance of crossed van't Hoff SS-MHHP. The effects of convective heat transfer, thermal mass of the reaction beds and variation in heat transfer fluid temperature along the axial direction of the reactor are considered in the energy equation.

2. Physical model and principle of operating

The operating principle of SS-MHHP working on cross van't Hoff configuration shown in Fig. 1 is analogous to the conventional MHHP system [2–7,9,10]. In the conventional MHHP, during the regeneration period, the heat of absorption is rejected at atmospheric ambient temperature, where as in the crossed van't Hoff MHHP, the absorption heat of refrigeration hydride (at $T_H^{'}$) contributes for desorbing the hydrogen from regeneration hydride. This technique can significantly reduce the driving heat supplied to the heat pump, thereby achieving higher coefficient of performance. The design details of the reaction beds used for the present analysis are shown in Fig. 2. It consists of a pair of two similar reactors (A and B). Reactor A is filled with regeneration alloy and reactor B is filled with refrigeration alloy. The inner most tube of 12 mm outer diameter and 475 mm length acts as the hydrogen filter. The purpose of the filter is to distribute the hydrogen uniformly through out the reaction bed during the absorption process and to prevent the hydride particle being carried away by the hydrogen during the desorption process. Metal hydride particles (40–60 μm) are filled in the space between the inner reaction tube and the filter section. The heat transfer fluid flows spirally around the outer peripheral tube of 2.0 mm annular gap. These two reactors are coupled by a connecting tube with a control valve. Hydrogen gas can flow freely between the reaction beds, when the valve is opened. The dimensions of the connecting tube are 300.0 mm length and 3.0 mm internal diameter. During the hydrogen transfer process, pressure drop in the connecting pipe is calculated and its value is found to be negligible. Reaction beds considered in the present investigation is axi-symmetric. Hence, only the top half of the reaction bed (shown in Fig. 3) is modeled.

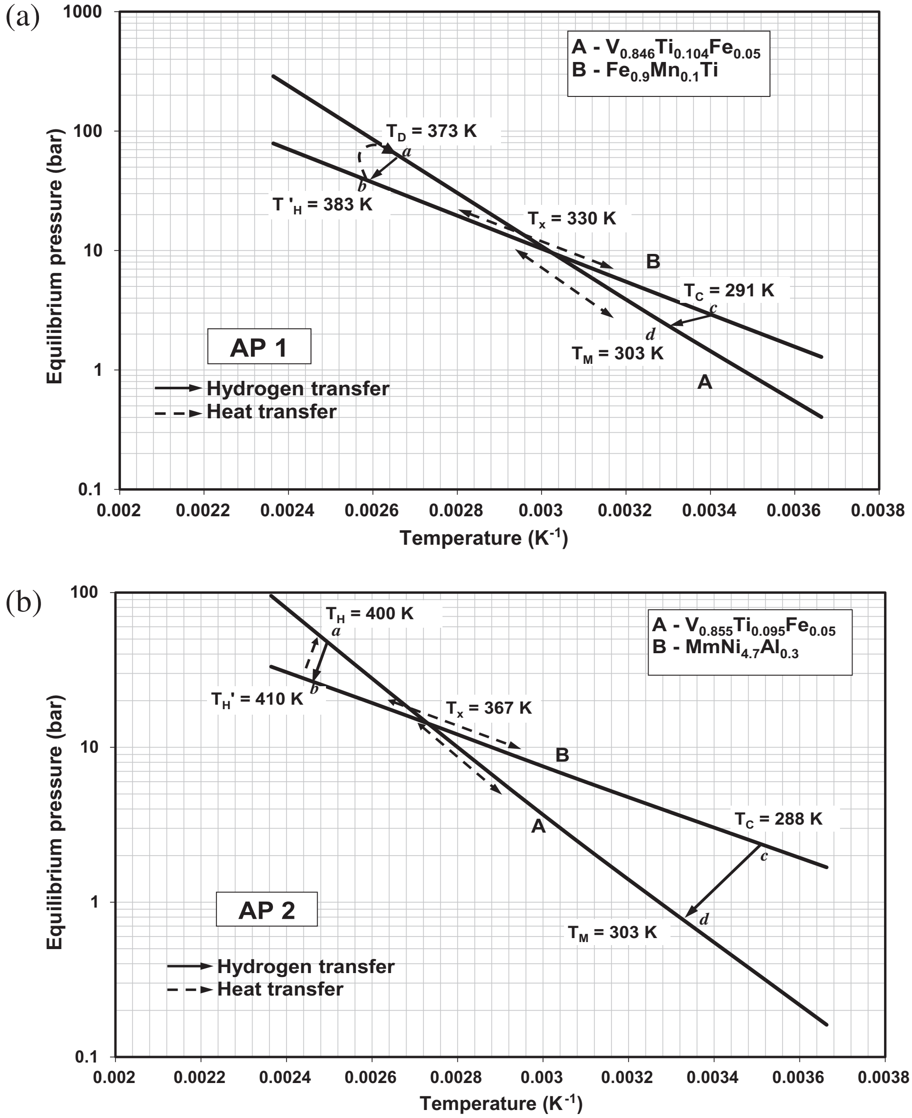

Fig. 1 – Operation of SS-MHHP on crossed van't Hoff configuration of (a) $V_{0.846}Ti_{0.104}Fe_{0.05}/Fe_{0.9}Mn_{0.1}Ti$ and (b) $V_{0.855}Ti_{0.095}Fe_{0.05}/MmNi_{4.7}Al_{0.3}$.