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Performance analysis of a single stage four bed metal hydride cooling system, part B: influence of heat recovery

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Abstract

Influence of heat recovery on the performance of a single stage multi-bed metal hydride cooling system is studied with $Zr_{0.9}Ti_{0.1}CrFe$ and $Zr_{0.7}Ti_{0.3}CrFe$ as high and low temperature alloys respectively. The heat recovery cycle effectively utilizes the sensible heat contained in the beds at the end of desorption and resorption processes thereby reducing the heat input and increasing the refrigerating effect. Compared to the basic cycle, the coefficient of performance of heat recovery cycle improves by about 15% to over 75% depending on the operating temperatures.

Keywords: Metal hydride; Heat recovery; Cooling system

1. Introduction

Detrimental environmental effects of conventional refrigeration systems and the need for utilizing low grade thermal energy have drawn attention towards metal hydride cooling systems. However, the performance of metal hydride based systems has been found to be poorer than that of other heat operated systems. Effective management of heat and mass transfer in the hydride beds is one possible means of improving the performance.

While many heat recovery studies on conventional solid sorption systems have been reported [1–4], it is observed that such studies on metal hydride systems are scarce. The main difference of metal hydride systems compared to conventional solid-sorption systems is that hydrogen does not condense.

The concept of mass recovery in single stage four-bed metal hydride cooling systems has been studied recently by the authors [5]. This paper brings out the influence of heat recovery on a single stage four-bed metal hydride cooling system. Analysis of the thermodynamic cycle and comparison of its performance with that of the basic cycle are presented.

2. Operation of the systems

A schematic of the metal hydride cooling system with heat recovery is shown in Fig. 1. Reactors A_1 and A_2 contain the high temperature alloy while B_1 and B_2 contain the low temperature alloy. The operation, analysis and computational procedure of the basic cycle are described recently by the authors [5]. The Van't Hoff plot for the heat recovery cycle is shown in Fig. 2. The heat recovery cycle operates as follows

Step 1: Initially A_1, B_1, B_2 and A_2 are at state points 1, 2, 3 and 4, respectively. A_1 is maintained at T_h by heating it from an external source while B_2 is connected to the cooling load at T_c. At the same time both B_1 and A_2 are at T_m. Hydrogen transfer take place from A_1 to B_1 and B_2 to A_2, respectively. The desired cold output is thus obtained at low temperature T_c. The concentration and pressure of A_1 and B_2 decrease while those of A_2 and B_1 increase. At the end of this step A_1, B_1, B_2 and A_2 are at 1′, 2′, 3′ and 4′, respectively.

Step 2: The beds are isolated from the external heat transfer circuits and heat transfer fluid is circulated between A_1 and A_2 and also between B_1 and B_2. At ideal conditions, heat recovery can take place till the temperatures of beds A_1 and A_2, and also those

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Nomenclature

A	high temperature metal hydride bed
B	low temperature metal hydride bed
COP	coefficient of performance
C	specific heat . . . . kJ·kg^{-1}·K^{-1}
$f_{s,298}$	slope factor at 298 K (= 0.8)
H/M	atoms of hydrogen per molecule of metal alloy
ΔH	enthalpy of formation . kJ·(mol of hydrogen)$^{-1}$
k	rate of variation of f_s with temperature, = −0.004
M	molecular weight of alloy . . . . kg·kmol^{-1}
m	mass of the bed . . . . kg
N	alloy atoms per mole (for AB_2, $N = 3$)
n	moles of hydrogen
P	equilibrium pressure of bed . . . . bar
Q	total heat . . . . kJ·(kg of alloy A)$^{-1}$
q	sensible heat . . . . kJ·(kg of alloy A)$^{-1}$
ΔS	entropy of formation . . . . kJ·(mol of hydrogen)$^{-1}$·K^{-1}
T	temperature . . . . °C
X	concentration of hydrogen (atoms of hydrogen per molecule of alloy)

Subscripts

b	hydride bed
c	low temperature
h	high temperature
int1	temperature of A_1, A_2 after heat recovery
int2	temperature of B_1, B_2 after heat recovery
m	intermediate temperature
mid	mid-point of the plateau
R	with heat recovery
W	without heat recovery

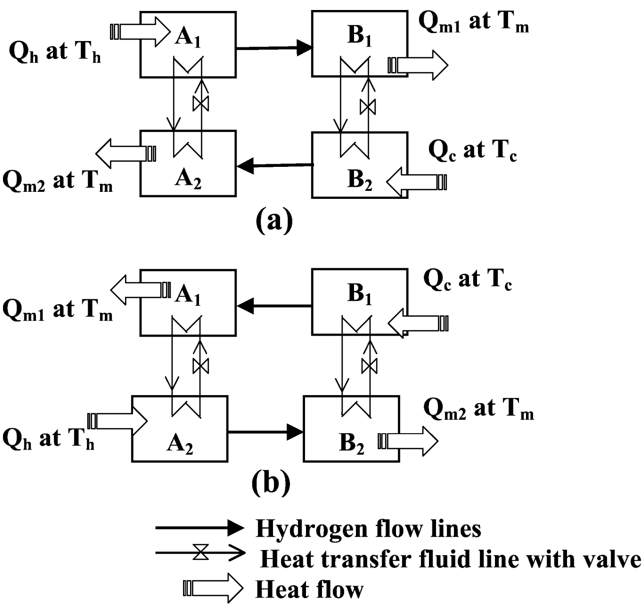

Fig. 1. Schematic diagram of the four bed single stage metal hydride cooling system: (a) First half cycle; (b) Second half cycle.

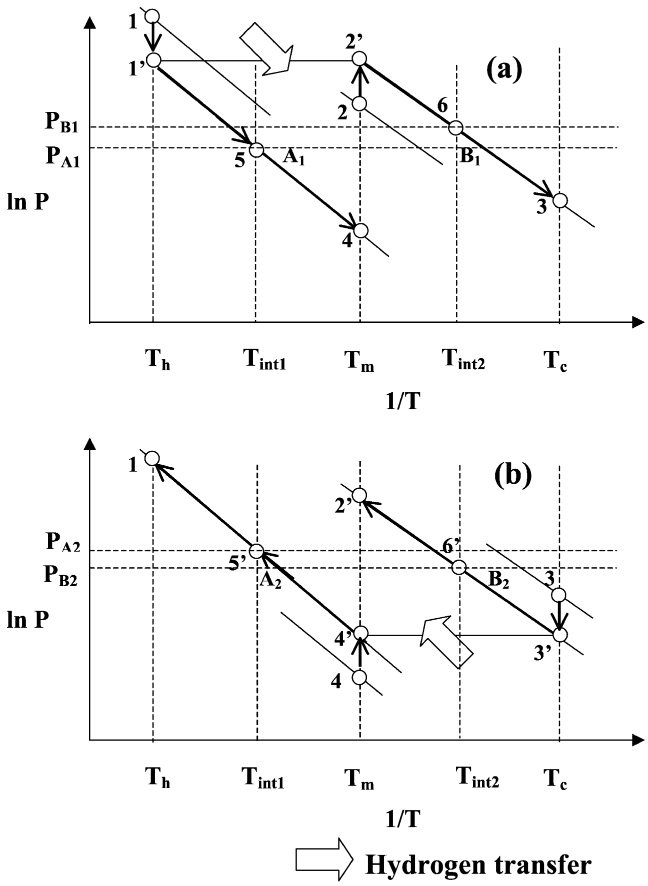

Fig. 2. Plot of heat recovery cycle on the Van't Hoff chart for the first half cycle: (a) For beds A_1 and B_1; (b) For beds A_2 and B_2.

of B_1 and B_2 are equalized. A_1 and A_2 attain a mean temperature of T_{int1} while B_1 and B_2 attain T_{int2}. At this stage, A_1, A_2, B_1 and B_2 are at 5, 5′, 6 and 6′, respectively. Now sensible heating of bed A_2 from T_{int1} to T_h and sensible cooling of bed B_1 from T_{int2} to T_c takes place. Then A_2, B_2, B_1 and A_1 are at state points 1, 2, 3 and 4, respectively.

The above steps are repeated in the second half cycle with A_2, B_2 taking the place of A_1, B_1, respectively.

3. Assumptions

The following simplifying assumptions are made in this analysis: