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Numerical study of the dynamic behavior of a metal hydride pump

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ABSTRACT

Metal hydride pump (MHP) is one of the unconventional pumping systems. This type of pump converts thermal energy into mechanical energy using hydrogen as a working fluid to pump liquid for low head and high discharge by Solovey AI and Frovol VP (2001).[1]. The MHP has been worked out in order to solve problems of availability of electricity or fossil energies in certain freestanding regions.

In the present paper a numerical study of the dynamic behavior of MHP has been carried out with Mg_2N_i alloy at various operating parameters (Desorption temperature, absorption temperature, gear ratio, pump head and surfaces of piston). This study shows that, with MHP, it is possible to pump as much as 1375 l of water in 10,000 s at a desorption temperature of 623 K and for pumping head of 5 m using one kg of Mg_2N_i. Also a simulation was performed to optimize the pumping time by the integration of a heat exchanger in the metal hydride bed. In addition, a comparison between results obtained with steady and unsteady models is done.

Introduction

Recent studies have shown that many of AB_5 type alloys are used in water pumping applications [2]. Also, many alloys ($LaNi_{4.9}Ge_{0.1}$,$MmNi_4Al$,$LaNi_{4.8}Sn_{0.2}$,$MmNi_{4.2}Al_{0.8}$ and $La_{0.8}Ce_{0.2}$-$Ni_{4.25}C_{0.5}Sn_{0.25}$) where compared for a water pumping system [2]. It was found that $MmNi_4Al$ is the best. A study shows that, with $MmNi_4Al$, a heat source temperature as low as 100 °C can be used to pump water up to 10 m head. Furthermore, experiences have shown that a water pump system based on metal hydride can pump 800 l of water with a low heat source temperature of 80 °C [1,3]. Recently, Rajendra et al. [4] discussed, using a steady model, the performance of a metal hydride water pumping system using $LaNi_5$ as hydriding alloy. They assumed that the temperature within the metal-hydrogen reactor is constant and equal to the heating temperature and surfaces of hydrogen and pumping piston are equal. The results obtained in this work appear to be promising. For example, the system could pump 130 l of water/kg-cycle to a head of 10 m using a heating temperature as low as 100 °C. However, the required time of the pumping process, the time evolution of specific water discharge and the pumping time details cannot be determined using steady model.

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Nomenclature

C_p	Specific heat, (J kg^{-1} K^{-1})
$\dot{m}$	Hydrogen mass absorbed/desorbed, (kg m^{-3} s^{-1})
E_d	Desorption activation energy, (J/mol)
C_d	Desorption rate constant, (s^{-1})
ρ_{emp}	Free metal hydride density,(kg m^{-3})
r	Radial coordinate (m)
z	Axial coordinate (m)
R	Reactor ray, (cm)
H	Reactor height, (cm)
ΔH	Enthalpy of formation,(J/mol H_2)
ΔS	Entropy of formation (J/K mol H_2)
ρ	Density, (kg m^{-3})
λ	Thermal conductivity, (W m^{-1} K^{-1})
ε	Porosity (dimensionless)
A	Area, (m^3)
F	Force, (N)
f_s	Slope factor, (dimensionless)
T_f	Heating temperature
G	Gear ratio
M	Molar mass, (g/mol)
P	Pression, (bar)
R_g	Universal gaz constant,(J/mol K)
h	Head, (m)
V	Volume, (l/Kg-cycle)
T	Temperature
W	Weight, (N)
Z	Piston displacement, (m)
X	Concentration, (dimensionless)
γ	Adiabatic index, (dimensionless)
n_{H_2}	Number of moles of hydrogen, (mol/Kg of metal)
Q	Heat input, (KJ/Kg-cycle)
η	Pumping efficiency, (dimensionless)

Subscripts

de	Desorption
g	Gaz
eq	Equilibrium
ab	Absorption
e	Expansion
f	Final
h	Hydrogen (piston/cylindre)
p	Pump (piston/cylindre)
i	Initial
d	Discharge
t	Total
Av	Average
min	Minimal
sat	Saturation

Therefore, the aim of the present work is to study the dynamic behavior of MHP using an unsteady model (we take into account the time space evolution of temperature, pressure and hydrogen concentration within the reactor). The remainder of this article is divided into three sections. First a mathematical model that describes the dynamic behavior of the pump is developed. Then, a numerical simulation is used to present the time evolution of the specific water discharge and to evaluate the impact of different parameters (heating temperature, desorption gear ratio, absorption temperature, surfaces of hydrogen and pumping pistons, total pumping head and expansion gear ratio) on the performance of water pumping system. Also, a simulation was devoted to improve the pumping time by changing the form factor and the geometric configuration of the reactor. Finally, a comparison between results obtained with steady and unsteady models was performed for different metal hydride masses.

Operating concept of MHP

The schematic diagram of the used MHP is presented in Fig. 1. As shown in the figure, this system may be divided into two modules, namely, the hydride module and the pumping module. The first one is composed of a frictionless piston-cylinder arrangement with dead weights and a metal hydride reactor (MHR) which is immersed in a cooling/heating bath maintained at constant temperature. This module converts the heat input into mechanical energy (movement of the piston). The pumping module is also composed of a frictionless piston–cylinder arrangement with dead weights, and two tanks: one for suction and the other for delivery joined by connecting pipes and check valves. These two modules are coupled by a gear system which enables to adjust the ratio between the forces and the displacements of pistons of the two modules. Engaging, disengaging and changing gear ratio of the gear system can be similar to the conventional one used in automobiles.

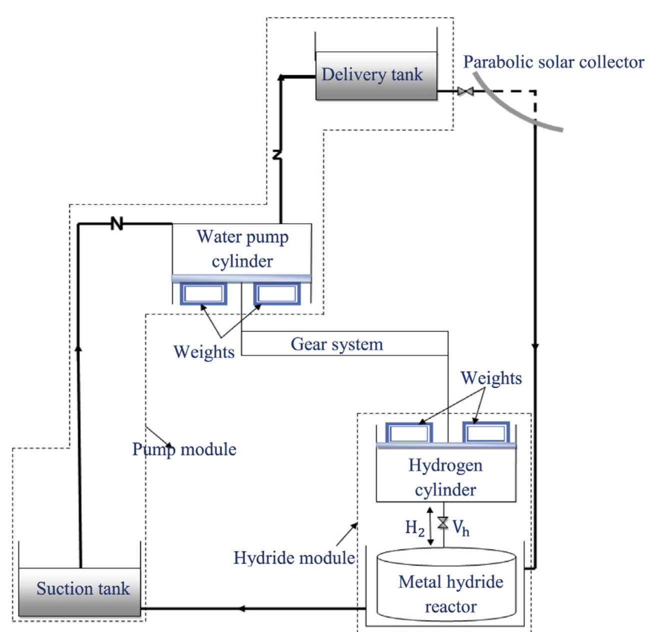

Fig. 1 – Schematic of metal hydride water pumping system.