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Characteristics of heat–hydrogen gas energy conversion and hydrogen gas transportation using hydrogen absorbing alloy

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Abstract

Heat–hydrogen pressure conversion techniques and techniques for hydrogen gas transport over a long distance have been investigated to develop elemental technologies required for constructing a high-efficiency system to convert waste heat generated in industrial areas into hydrogen gas energy using hydrogen absorbing alloys. To efficiently convert heat into hydrogen gas energy using hydrogen absorbing alloys, we studied the effect of the use of a plate fin type alloy fill vessel and heat accelerators (copper, aluminium, and magnesium particles) mixed in the alloy layer. We also studied the characteristics of the hydrogen gas being transported through a 1-km piping unit.

Keywords: Heat–hydrogen pressure conversion; Hydrogen gas transportation; Hydrogen absorbing alloy; Heat accelerators; Magnesium particle

1. Introduction

We are currently developing elemental technologies required for constructing a high-efficiency system to convert waste heat generated in industrial areas into hydrogen gas energy using hydrogen absorbing alloys [1–3]. Such a system should enable transport for a long distance of the heat of the resultant low pressure hydrogen gas from the source of waste heat. One of the key technologies is heat–hydrogen gas pressure conversion technology. To efficiently convert heat into hydrogen gas energy using hydrogen absorbing alloys, we studied the effect of the use of a plate fin type alloy fill vessel and heat accelerators (copper, aluminium, and magnesium particles) mixed in the alloy layer. We also studied the characteristics of the hydrogen gas being transported through a 1-km piping unit.

2. Experimental

2.1. Improvement of techniques for heat transfer of hydrogen absorbing alloy layers

The experimental apparatus used for the study of the effect of the heat accelerators mixed in the hydrogen absorbing alloy layer is shown in Fig. 1. The $Ti_{0.4}Zr_{0.6}Cr_{0.8}Fe_{0.7}Mn_{0.2}Ni_{0.2}Cu_{0.03}$ alloy used in this study was crushed into powders of 50–200 mesh in size. As the accelerator, 10 wt.% of copper, aluminium or magnesium particles 200 mesh in size was mixed in the alloy layer. Dimensions of the alloy layer were 130 mm diameter and 3 mm thickness. The amount of hydrogen absorbed was evaluated from the pressure drop in the container.

Plate fin type units and bare tube type units were assembled with about 3–5 kg of hydrogen absorbing alloy and the heat transfer characteristics of the units were investigated.

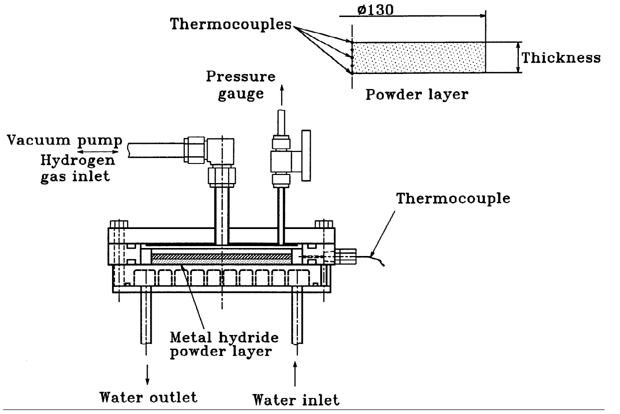

Fig. 1. Schematic of the apparatus used to test the hydrogen absorbing alloy layer.

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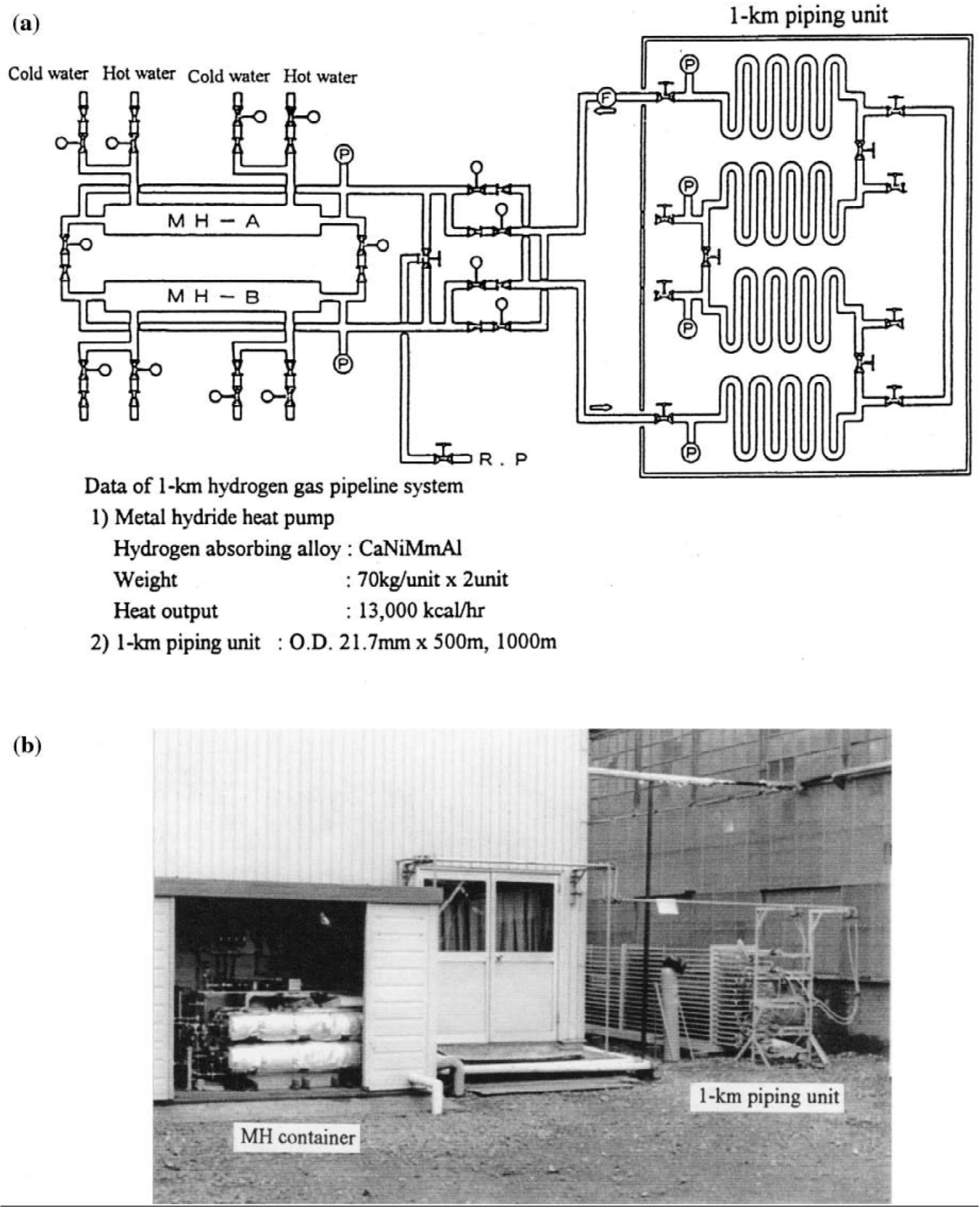
2.2. Investigations of hydrogen gas transported through pipes for a long distance

Fig. 2 presents the hydrogen gas transport experimental facility using a 1-km hydrogen gas pipeline unit. The metal hydride container used in this system is filled with 70 kg of alloy. Heat transport (hydrogen transport) was achieved by simply connecting two metal hydride containers of the same type with a single 1-km pipe.

3. Results and discussion

3.1. Effects of heat accelerators mixed in the alloy layer

When 10 wt.% copper, 10 wt.% aluminium or 10 wt.% magnesium particles were mixed in the alloy layer as a heat accelerator, the rate of hydrogen absorption was increased as shown in Fig. 3. As a result of this investigation, we found that the hydrogen gas absorbing rate



Data of 1-km hydrogen gas pipeline system

1) Metal hydride heat pump

Hydrogen absorbing alloy : CaNiMmAl

Weight : 70kg/unit x 2unit

Heat output : 13,000 kcal/hr

2) 1-km piping unit : O.D. 21.7mm x 500m, 1000m

Fig. 2. (a) Appearance of experimental facility. (b) Schematic diagram of experimental facility.

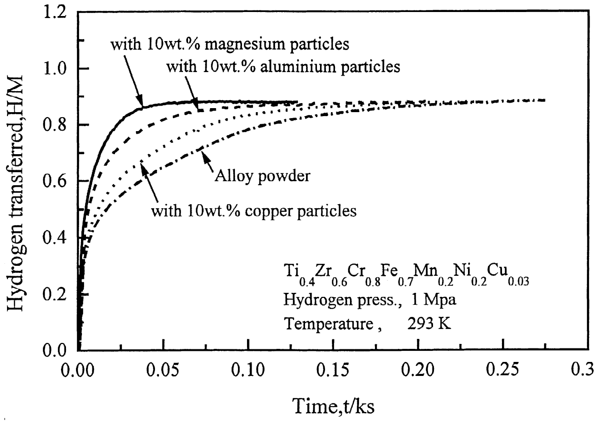


Fig. 3. Hydrogen transferred vs. time for the alloy with copper, aluminium or magnesium particles.

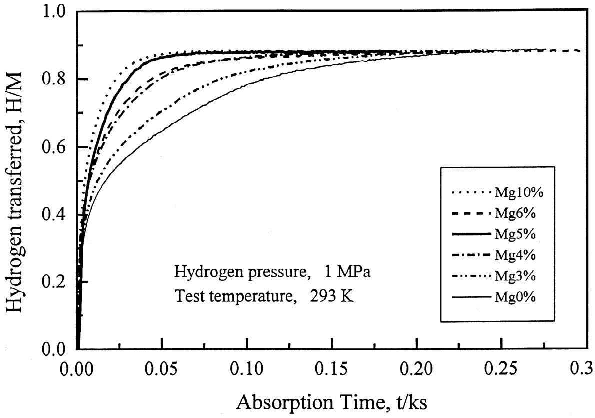


Fig. 5. Effect of magnesium particles mixed in the hydrogen absorbing alloy layer on hydrogen transferred vs. time at 293 k.

of the alloy layer mixed with magnesium particles was larger than that of the hydrogen absorbing alloy layer mixed with other accelerators. Fig. 4 shows scanning electron microscope (SEM) photographs of the alloy powders after the experiments. The particle diameter of the $Ti_{0.4}Zr_{0.6}Cr_{0.8}Fe_{0.7}Mn_{0.2}Ni_{0.2}Cu_{0.03}$ alloy after the experiments became about 10 μm because of pulverization. The particle diameter of magnesium particles used as an accelerator is slightly larger than those of other accelerators. When 3–10 wt.% magnesium particles were mixed in the alloy layer as a heat accelerator, the heat transfer rate of the alloy layer increased as shown in Fig. 5 and the temperature difference between the alloys and heat medium during heat–hydrogen gas conversion was reduced. In the case of 10 wt.% magnesium particles, the hydrogen gas absorbing rate was larger than that of the

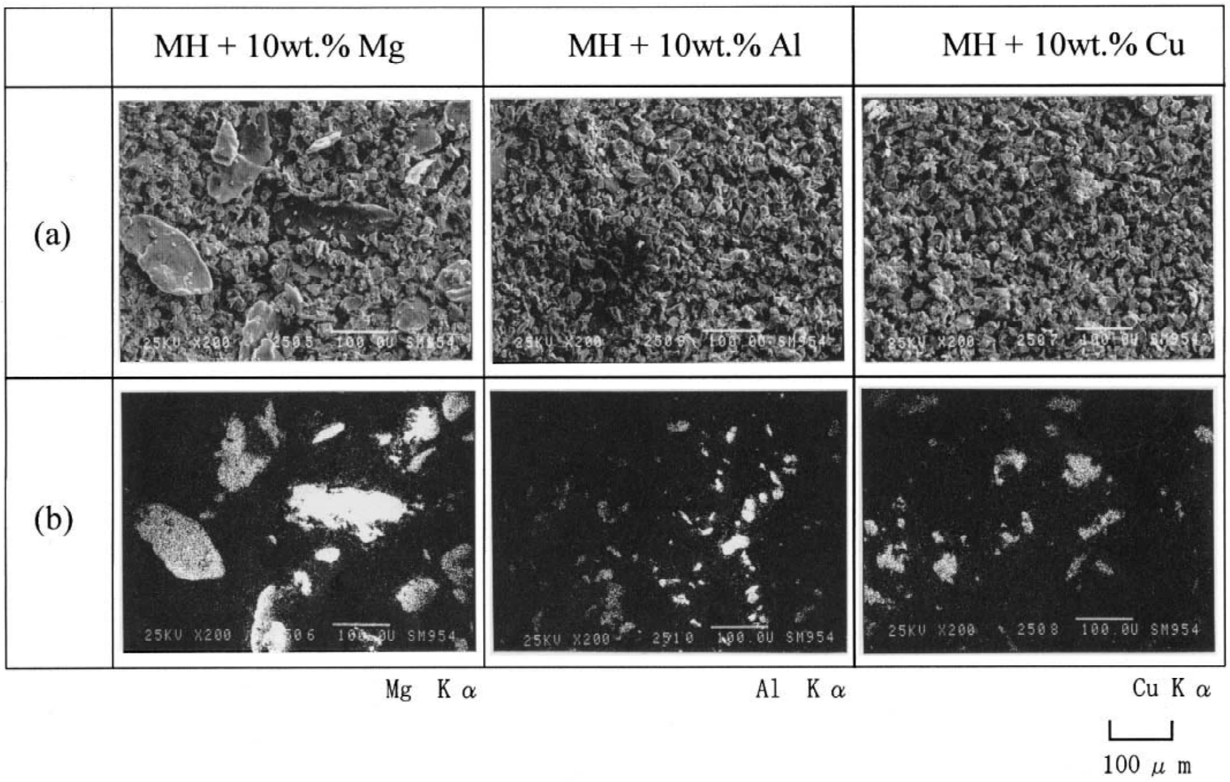


Fig. 4. SEM images and characteristic X-ray images for the alloy with copper, aluminium or magnesium particles.

others. But the total volume of hydrogen gas transferred was smaller than that of the others because the volume of magnesium particles was large and so the weight of hydrogen absorbing alloy in the alloy layer was small. Fig. 6 shows the hydrogen transfer ratio based on the hydrogen transfer of the hydrogen absorbing alloy layer itself. As a result of this investigation, we determined that the optimum weight of magnesium particles mixed in the alloy should be set at about 5 wt.%.

3.2. Type of heat exchanger with hydrogen absorbing alloy

Plate fin type units (fin pitch: 1.0–1.6 mm) and bare tube type units (tube diameter 6 mm) were assembled with the hydrogen absorbing alloy and the heat transfer characteristics of each unit and effects of the thickness of the alloy layer on the hydrogen absorbing rate were investigated. Fig. 6 shows that the use of the plate fin type hydrogen absorbing alloy fill vessel greatly improved heat transfer performance per unit weight of the alloy compared with bare tube type units, and reduced the temperature difference between the alloys and the heat medium during heat–hydrogen gas energy conversion. When 5 wt.% magnesium particles were added to the alloy, heat transfer in each container was improved. The positive effect of the use of the heat accelerator (magnesium particle) was confirmed.

3.3. Hydrogen transport and hydrogen–heat conversion techniques

The behaviour of the hydrogen gas discharged from the hydrogen absorbing alloy and transported through pipes for a long distance was investigated and compared by means of a hydrogen transport evaluation device and simulation. Using a 1-km hydrogen gas pipeline system, the relationship between the hydrogen gas flow and output temperature of water and hydrogen gas pressure change during the heat transport operation was investigated. The hydrogen gas flow rate and water temperature output showed a linear relationship. While hydrogen gas is introduced into the unit, hydrogen gas pressure in the unit changes with the plateau pressure of the hydrogen absorbing alloy. Using this experimental facility, 1200 kcal cycle^{-1} (1.2 ks) of thermal power was transported through the 1-km piping unit. The possibility of heat transport using a hydrogen absorbing alloy and a long-distance (1-km) hydrogen gas pipeline was confirmed. Fig. 7 shows operation results for the experimental facility and simulation results computed by a commercial compressible-flow simulation program. The simulation results show a reasonable correlation with the experimental data, and the simulator developed may be useful for design purposes.

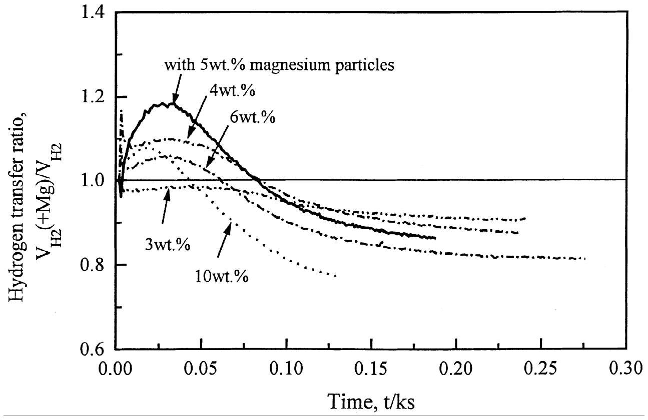


Fig. 6. Hydrogen transfer ratio $VH_2(+Mg)/VH_2$ vs. time.

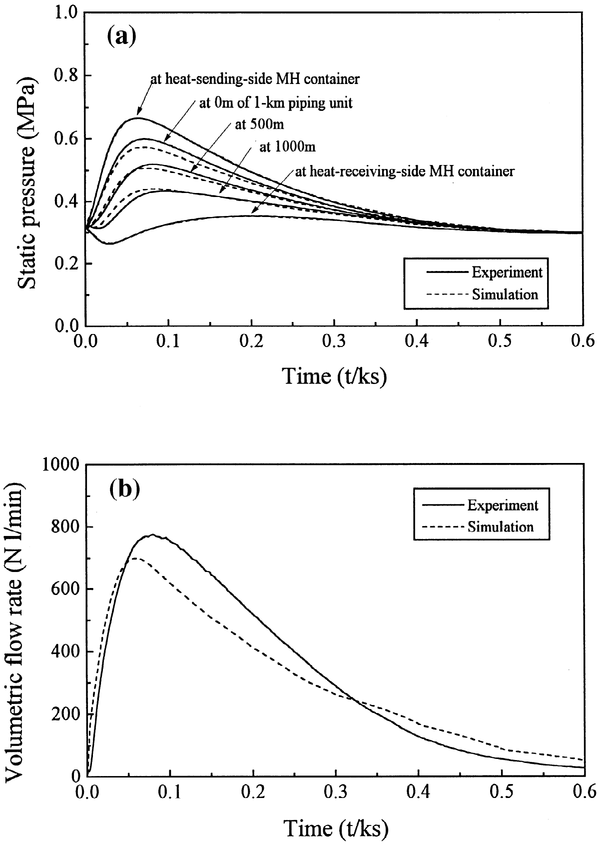


Fig. 7. Periodic behaviour of hydrogen gas flow rate and pressure. (a) Hydrogen pressure profile at various points. (b) Hydrogen gas flow rate at inlet of heat-receiving-side MH container.

4. Conclusions

When copper, aluminium, or magnesium particles are mixed in a hydrogen absorbing alloy layer as a heat accelerator, heat transfer in the alloy layer is accelerated and the rate of hydrogen absorption is increased. The optimum weight of the heat accelerator (magnesium particles) was confirmed by experiments using a heat exchanger with a hydrogen absorbing alloy. The possibility of heat transport using a hydrogen absorbing alloy and a long-distance (1-km) hydrogen gas pipe line unit was confirmed.

Acknowledgments

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