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Experimental Study on a Metal Hydride Tank for the Totalized Hydrogen Energy Utilization System

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Abstract

We have been performing research on a Totalized Hydrogen Energy Utilization System (THEUS) which is composed of a Unitized Reversible Fuel Cell (URFC) and metal hydride tanks. THEUS is very similar to the regenerative fuel cell system located at the Savannah River National Laboratory (SRNL) but it utilizes the thermal energy from the system to improve the total system efficiency. AIST and SRNL started a collaborative research program on THEUS in 2010 under the Clean Energy Partnership Technology Program between METI and DOE. To initiate the project, a horizontal type metal hydride tank was developed. It had a double coil type heat exchanger and contained 50 kg of AB5 type metal hydride alloy. Absorption and desorption of 6,350 NL of hydrogen was successfully attained at an absorption rate of 11.8 NL/min and a desorption rate of 8.1 NL/min. The experimental results of the heat exchanging performance were compared with the results of a vertical type metal hydride tank which was developed in AIST in 2008. This paper introduces the experimental results of the metal hydride tank which is tested in SRNL.

Keywords: Mtal hydride Tank, Hydrogen storeage, Stress measurement, Reaction heat, Absorption, Desorption

Introduction

We have been performing research on a Totalized Hydrogen Energy Utilization System (THEUS) under development for commercial buildings [1, 2]. THEUS is comprised of a Unitized Reversible Fuel Cell (URFC) [3, 4] and metal hydride tanks. During the night, this system produces gaseous hydrogen by

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operating the URFC in water-electrolysis mode, and it stores the gas in the metal hydride tanks. During the day, the URFC operates in fuel-cell mode by utilizing the stored hydrogen to supply electricity to the building; this is the basic concept of the system. THEUS is very similar to the regenerative fuel cell system located at the Savannah River National Laboratory (SRNL)[5] but it utilizes the thermal energy from the system to improve the total system efficiency. AIST and SRNL started a collaborative research program on THEUS in 2010 under the Clean Energy Partnership Technology Program between METI and DOE. To initiate the project, a horizontal type metal hydride tank, which had a double coil type heat exchanger, was developed in AIST and tested in Center for Hydrogen Research (CHR) building in SRNL.

Experimental set-up

Fig. 1 shows a schematic of the horizontal type metal hydride tank. The total length is 1 m, the outer diameter is 165.2 mm, and the inner diameter is 155.2 mm. 50kg of $MmNi_5$ metal hydride alloy is contained in the tank and the total weight of the tank is approximately 85 kg. A double coil type heat exchanger, which is made of copper, was installed. The total length of the copper tube is 19.7 m and the diameter is 1/2 inch. A sheath thermocouple, which has three measurement points, was inserted to measure the temperature in the tank. Three thermocouples were also set at the outside of the tank. The temperatures of the circulation water were measured by using the platinum resistance thermometers at the inlet and the outlet of the circulation water. The inner pressure of the tank was measured using a pressure transducer. The safety valve was set to 4.0 MPa. To measure the stress on the tank, two strain gauges were set at the side and the bottom in the middle portion of the tank. Each strain gauge measured two directions of stress, one in the circumference direction and the other in the axial direction of the tank. As for the hydrogen injection/extraction tube, an original design tube was manufactured to reduce the cost of the tank. A double screen stainless mesh was installed between the inner wall of the tank and the metal hydride for enhancing the hydrogen injection and extraction.

The metal hydride tank was developed in AIST and shipped to SRNL. Fig. 2 shows a photograph of the experimental set-up installed in the Education Training and Development (ET&D) Lab. in the CHR. The hydrogen panel, the metal hydride tank, the circulation water control box, and the thermostat controller are shown in the photo. The metal hydride tank was covered with black foam insulation to prevent heat loss. The total weight of the metal hydride tank including the thermal insulator was about 90 kg. The hydrogen mass flow meter (Oval Model F-332S) and the control valve (Oval Model F-432S)

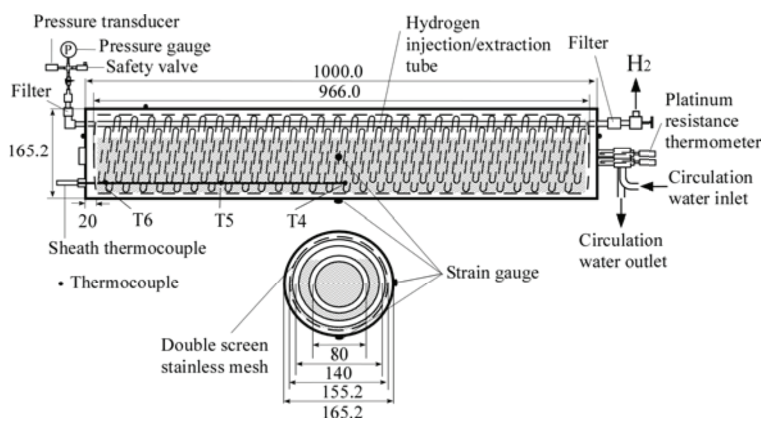

Fig. 1 Schematic of the metal hydride tank.

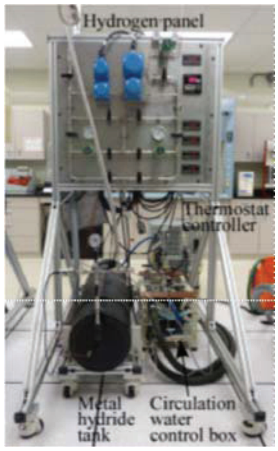

Fig. 2 Experimental set-up.

were located on the hydrogen panel. The temperature of the circulation water was maintained by the thermostat controller (Thermo Scientific ThermoFlex2500) and the mass flow rate was controlled using a mass flow meter (Keyence FD-SS2A) with a needle valve.

Result and Discussion

1. The stress measurement in activation process

Fig. 3 shows the results of the stress measurement for three activation processes. The stress values in the axial and the circumference directions at the side wall and the bottom wall are plotted

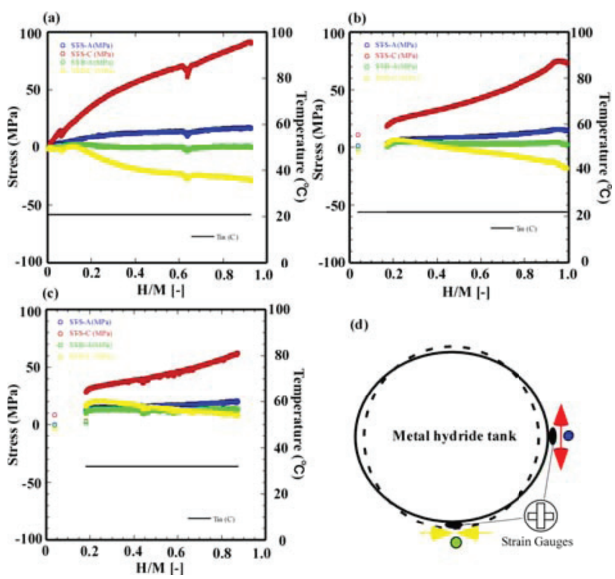

Fig. 3 Results of the stress measurements.

against composition, H/M. The inlet temperature of the circulation water is also shown in the figure. Figs 3a, 3b and 3c show the results for the first, second, and third absorption processes, respectively. It is noted that the stress value in the circumferential direction at the side wall is particularly large as compared with the others. During the first absorption, the stress value reached 91.9 MPa. But in the third absorption, the final stress value was 62.5 MPa. The magnitude of the stress became smaller as the number of activations increased. It is also noted that the stress values in the circumferential direction at the bottom showed negative values in Figs 3a and 3b. The bottom portion was subject to compressive stress. This suggests that the cross-sectional shape in the middle portion of the tank was elliptically-deformed in the absorption process as shown in Fig. 3d. On the other hand, the magnitude of stress in the axial direction is relatively small as compared with that in the circumferential direction. The proof stress of SUS316 stainless steel is 205 MPa. The measured maximum stress value was less than half of the proof stress.

2. Absorption and desorption test results

Fig. 4 shows the experimental results under the conditions of THEUS operation. In the absorption process, the flow rate of the gaseous hydrogen was set to 10 NL/min, the temperature of the inlet circulating water was set to 32 degree C, and its flow rate was set to 0.96 L/min. On the other hand, during the desorption process, the flow rate of the gaseous hydrogen was set to 6.9 NL/min, the temperature of the inlet circulating water was set to 12 degree C, and the flow rate was set to 0.39 L/min. Fig. 4a shows the relationship between the pressure in the tank and H/M, the so-called pressure-composition or "P-C curve". The composition of 0.18 was selected as the starting point of this experiment, and 5400 NL of hydrogen was absorbed and desorbed. The experiment was performed between an H/M of 0.18 to 0.88. Fig. 4b and Fig. 4c show the temperatures in each position in the tank, and the inlet temperature and the outlet temperature of the circulation water in cases of absorption and desorption, respectively. The temperature data in the absorption process remains relatively steady, however, in the last half of desorption process, the temperatures T5 and T6 slightly decrease. The recovery heat was 5.97 MJ throughout the absorption process, and 5.03 MJ throughout the desorption process. The metal hydride reaction heat recovery rate, ε, was 90.2 % in case of absorption, and it was 79.5 % in the case of desorption, respectively. The recovery rate is almost the same as that of the vertical type metal hydride tank, which was developed in AIST in 2008 [1].

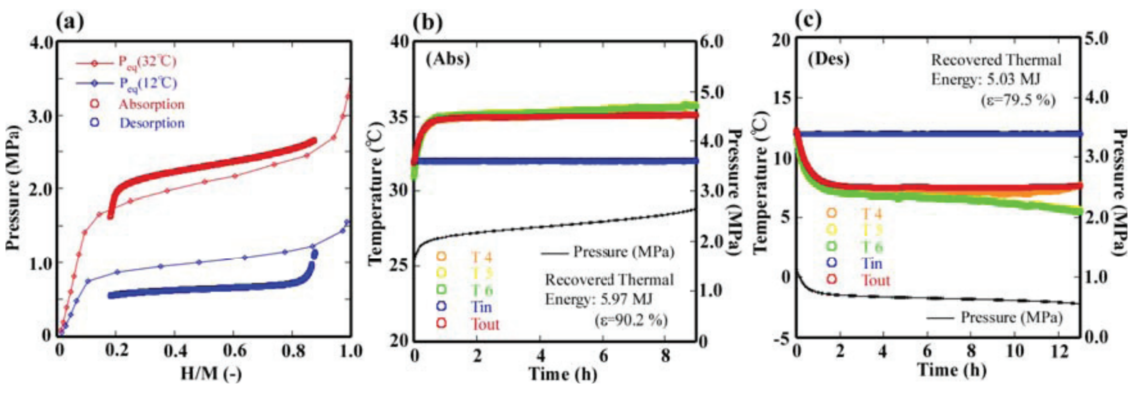

Fig. 4 Experimental results for THEUS operation. (a) P-C Curve. (b) Temperature in the tank and circulation water in case of absorption. (c) Temperature in the tank and circulation water in case of desorption.

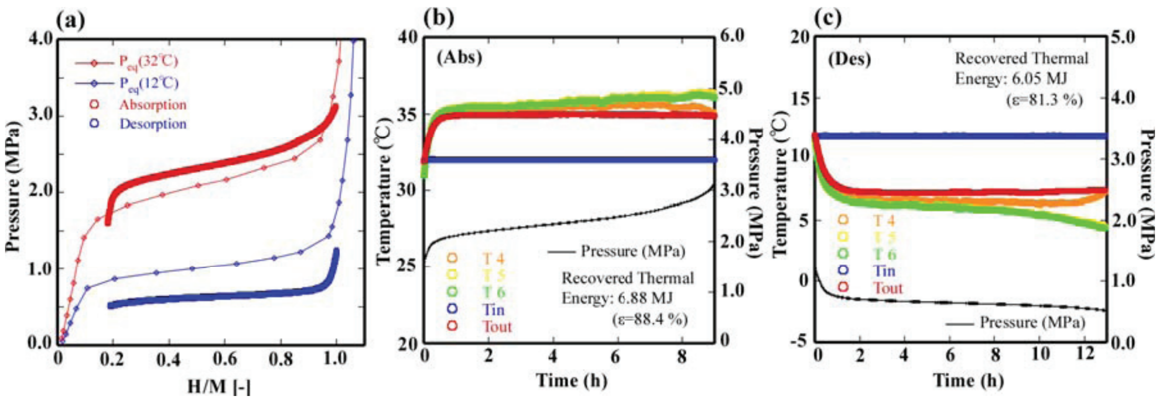

Fig. 5 Experimental results for THEUS operation. (a) P-C Curve. (b) Temperature in the tank and circulation water in case of absorption. (c) Temperature in the tank and circulation water in case of desorption.

Fig. 5 shows the results when 100% of hydrogen storage capacity was used, which is an H/M of 1.0. 6350 NL of hydrogen was absorbed from the initial composition, H/M=0.18, and desorbed from H/M=1.0. Fig. 5a shows the P-C curve. The hydrogen flow rate was 11.8 NL/min and the circulation water flow rare was 1.13 L/min at 32 degree C during the absorption process. During the desorption process, the hydrogen flow rate was 8.1 NL/min and the circulation water flow rate was 0.46 L/min at 12 degree C. Figs. 5b and 5c show the temperature in the tank and the inlet temperature and the outlet temperature of the circulation water in both cases. These figures indicate almost the same temperature profiles shown in Figs 4b and 4c. The recovery heat was 6.88 MJ throughout the absorption process, and 6.05 MJ throughout the desorption process. The reaction heat recovery rate, ε, was 88.4 % in the case of absorption, and 81.3 % in case of desorption, respectively.

Conclusions

A metal hydride tank which, demonstrated very good heat exchange performance, was successfully demonstrated. The safety of the metal hydride tank with respect to expansion stresses was confirmed. The cross-sectional shape in the middle portion of the tank was shown to undergo elliptical☐ deformation during the absorption process. The absorption and the desorption tests demonstrated reaction heat recovery rates over 79%. The recovery rate is almost the same as that of the vertical type metal hydride tank, which was developed in AIST in 2008. However, the production cost of the tank (except the metal hydride) was less than half of the vertical type tank production cost. The major factors of the cost reduction are the reduction in weight of the tank and the new designed hydrogen injection/extraction tube (Japanese patent is pending), which worked very well.

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