PROPAGATION OF WAVES OF METAL-HYDRIDE THERMAL CONVERSION IN BLOWN-THROUGH POROUS MEDIA

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A method of metal-hydride thermal conversion that is an alternative to the traditional method is proposed and investigated. The unlike poles of metal-hydride thermal converters are distributed in pairs inside parallel channels. The channels are blown through with a heat-transfer agent. Thermal conversion develops as a set of successive heat waves. By a numerical-modeling method it is shown that the maximum thermal effect is attained in synchronous motion of the heat wave and the heat source (or sink) that accompanies the phase transition in the succession of metal-hydride poles. The results are presented in a form convenient for prediction of the thermal and energy efficiency of the proposed thermal-conversion method in real devices.

The methods of sorption and chemisorption thermal conversion continue to be a serious alternative to vapor-compression methods, since they make it possible to use heat energy instead of electric or mechanical energy, including especially sources of low-potential waste heat. However because of low thermal efficiency, bulky equipment, and the difficulty of realizing the sorption cycle of thermal conversion these methods have failed to find sufficient application up to now.

Certain hopes have been pinned on metal-hydride thermal conversion, which belongs to the chemisorption type of methods and results from the discovery of intermetallic alloys such as LaNi₅, FeNi, and Mg₂Ni, capable of interacting with hydrogen rapidly and reversibly [1, 2]. For some alloys, we do not observe any restriction on the rate of the reaction with hydrogen up to −100°C [3]. The heat of the hydride-formation reaction, referred to unit mass of sorbed matter (in this case, hydrogen), exceeds the heat of phase transition for water and Freon by approximately an order of magnitude. The hydrides of these alloys contain large amounts of hydrogen. The density of the hydrogen that is distributed in the crystal lattice under normal conditions can be higher than the density of liquid hydrogen [11].

The present investigation is devoted to the development of a new thermal-conversion method in which the indicated advantages of a sorption hydride system would be realized most fully.

Metal-Hydride Pair. Thermal conversion is realized on two unlike hydrides (a metal-hydride pair) [2, 4]. Each hydride of the pair is placed in a separate vessel. A metal-hydride converter is two hydride vessels connected by a channel for a free flow of hydrogen. In what follows these vessels will be called thermal-converter poles.

The hydrides differ from one another by the equilibrium hydrogen pressure. Over each hydride, taken separately, the latter is determined by the Van’t Hoff equation in the form [4]

\[
\ln p = \frac{\Delta S}{R} - \frac{\Delta h}{RT}
\]

or in the identical form

\[
p = p_{\text{max}} \exp \left( - \frac{\Delta h}{RT} \right).
\]

Curves of the pressure as a function of the temperature in accordance with formula (1) are presented qualitatively in Fig. 1a. The hydride in the pair that has a higher equilibrium temperature for the same pressure
Fig. 1. Hydrogen pressure vs. temperature for the hydrides of a metal-hydride pair (a) and schematic diagram of a traditional metal-hydride thermal converter (b): 1, 3) mean-temperature tanks; 2) high-temperature tank; 4) low-temperature tank.

Table 1. Equilibrium Properties of Hydrides

<table>
<thead>
<tr>
<th>No. of alloy</th>
<th>Alloy</th>
<th>$\Delta h$, kJ/mol</th>
<th>$\Delta S$, J/(mol·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MNi4.15Fe0.85</td>
<td>25.10</td>
<td>104.68</td>
</tr>
<tr>
<td>2</td>
<td>LaNi5</td>
<td>31.80</td>
<td>110.04</td>
</tr>
<tr>
<td>3</td>
<td>LaNi4.9Al0.1</td>
<td>32.64</td>
<td>110.46</td>
</tr>
<tr>
<td>4</td>
<td>LaNi4.75Al0.25</td>
<td>34.73</td>
<td>110.46</td>
</tr>
<tr>
<td>5</td>
<td>LaNi4.6Al0.4</td>
<td>36.40</td>
<td>109.20</td>
</tr>
<tr>
<td>6</td>
<td>LaNi4.5Al0.5</td>
<td>38.49</td>
<td>111.29</td>
</tr>
<tr>
<td>7</td>
<td>LaNi4.25Al0.75</td>
<td>44.35</td>
<td>117.99</td>
</tr>
<tr>
<td>8</td>
<td>LaNi4Al</td>
<td>47.70</td>
<td>118.83</td>
</tr>
</tbody>
</table>

is called the high-temperature hydride and is denoted by HM. The other hydride is called low-temperature and is denoted by LM. We will call the thermal-converter poles high-temperature and low-temperature, respectively. The equilibrium pressure over the high-temperature hydride for the same temperature is lower than that over the low-temperature one (Fig. 1a). A list of hydrides, that are recommended for compositing hydride pairs and their corresponding Van't Hoff constants is given in Table 1 [5, 6].

Principle of Operation for the Traditional Metal-Hydride Thermal Converter. In the general case, a metal-hydride pair operates with four heat tanks (Fig. 1b). The cycle of metal-hydride thermal conversion begins with the step of vapor charging, in which the vapor is brought to the active state. Let us assume that at the beginning of the process both poles are at the temperature of the mean-temperature tank $T_{\text{mean}}$. In the cooling cycle, the ambient medium usually acts as the mean-temperature tank. In Fig. 1a, this state corresponds to points 1 and 3. Then the high-temperature pole is brought in contact with the heat-transfer agent of the high-temperature tank, whose energy is used to charge the pair, while the low-temperature pole continues to be in contact with the mean-temperature tank 3. When the pressure in the high-temperature pole (point 2), as a result of its heating, rises above the pressure in the low-temperature pole (point 3), the hydrogen will begin to liberate itself from the hydride phase of the high-temperature pole and shift to the adjoining low-temperature pole. The heat of sorption released in this pole is removed to the mean-temperature tank.

The quantity of heat expended on pair charging can be calculated using the formula

$$Q_H = \Delta m_{H_2} \Delta h_{H_2} + m_{H_2} c_{H_2} (T_{\text{high}} - T_{\text{mean}}) + m_{P} c_{P} (T_{\text{high}} - T_{\text{mean}}).$$

(2)