Parametric studies on a metal hydride based hydrogen storage device

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Abstract

In this paper, a two-dimensional computational investigation of coupled heat and mass transfer process in an annular cylindrical hydrogen storage device filled with MmNi$_4$Al$_{0.4}$ is presented using a commercial software FLUENT 6.1.22. Hydrogen storage performance of the device is studied by varying the operating parameters such as hydrogen supply pressure and absorption temperature. Further, the effects of various bed parameters such as hydride bed thickness and overall heat transfer coefficient on the storage performance of the device are also studied. The average temperature of the hydriding bed and hydrogen storage capacity at different supply pressures showed good agreement with the experimental data reported in the literature. It is observed that as the hydriding process is initiated, the absorption of hydrogen increases rapidly and then it slows down after the temperature of the hydride bed increases due to the heat of the reaction. At any given absorption temperature, the hydrogen absorption rate and hydrogen storage capacity are found to increase with the supply pressure. The variation in the hydrogen absorption capacity, rate of reaction and temperature profiles at different supply pressures from 5 to 35 bar in steps of 5 bar are presented. Further, the effects of overall heat transfer coefficients from 750 to 1250 W/m$^2$K and cooling fluid temperatures from 288 to 298 K on hydrogen storage capacity are also investigated. It is shown that the heat transfer rate enhances the hydriding rate by accomplishing a rapid reaction. At the supply condition of 35 bar and 298 K, MmNi$_4$Al$_{0.4}$ stores about 13.1 g of hydrogen per kg of alloy.

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1. Introduction

In general, metal hydrides have relatively high heat of reactions and low thermal conductivities. The performance (defined as rates of absorption and desorption) of such systems depends on the rate at which the amount of heat is supplied to, or removed from the metal hydride. Therefore, an accurate modeling of the heat and mass transfer is of prime importance in optimizing the design of such systems. Coupled heat and mass transfer with chemical reaction takes place in such system and therefore the hydriding or dehydriding technique is quite complicated. The gas motion and physical properties of metal hydride also complicate the problem. Therefore, several experimental and numerical works exist on different aspects of the metal hydrides [1–14].

Lucas and Richards [1] developed one-dimensional mathematical model for predicting the performance of a hydrogen storage system, and solved the model considering one-dimensional transient heat conduction equation. However, their model did not include the heat of reaction, which is the main source of heat generation in the problem. There was large disagreement between their numerical results and experimental data due to simplification in the model adopted by them. Gopal and Murthy [2] investigated the effects of bed parameters such as bed thickness and effective thermal conductivity, and operating parameters such as cooling and heating temperatures on hydriding and dehydriding characteristics of LaNi$_4$Al$_{0.3}$ reactor using one-dimensional mathematical model. They concluded that for a good metal hydride system the heat transfer characteristics must be improved by keeping the bed thickness as small as possible and by improving the thermal conductivity of the bed. Subsequently, they have presented the experimental results of LaNi$_4$Al$_{0.3}$ hydride reactor during both the absorption and the desorption processes at different absorption and desorption temperatures [3]. Mayer et al. [4] discussed the properties of metal hydrides as well as the necessary requirements for their use in hydrogen storage applications.
They studied the effects of dimensions of the void/expansion data. Results showed good agreement with the available experimental data. The bed to the surrounding cooling fluid. Their computational model describing hydrogen desorption of a porous lanthanum/misch metal bed, in a closed reactor, and solved it numerically that the design of an industrial reactor needs the use of a three-dimensional modeling. Recently Phate et al. [14] carried out coupled heat and mass transfer analysis in hydride bed using a commercial code FLUENT 6.2. They considered bulk diffusion for mass transfer in the solid phase and not considered the plateau slope and hysteresis effects of the alloy in their model. It is evident from the literature that both the rates of absorption and desorption are controlled by heat and mass transfer characteristics of hydride bed. Many investigators [1–5,12] attempted to study such characteristics using one-dimensional and two-dimensional models without considering the effects of either convection or radiation. Most of the mathematical models available in literature are alloy dependent [7,10] and do not include the effects of plateau slope and hysteresis of the alloy in their model. They observed that the hydrogen storage capacities of both the alloys increase with supply pressure and the time taken for the absorption is found to be less at higher supply pressures. Subsequently, they have also carried out a comparative study of four candidate alloys, namely Mg +2 wt% Ni, Ti0.98Zr0.02V0.43Fe0.05Cr0.05Mn0.15, Zr0.5Ti0.5MnFe and MmNi4.5Al0.5 based on their hydrogen storage capacities and absorption rates. It was observed that Mg +2 wt% Ni has large hydrogen storage capacity of 7.4 wt% with an absorption rate of about 7.8 g/min at 20 bar. Marty et al. [13] presented a numerical approach for the prediction of heat and mass transfer in a hydride reactor during the absorption of hydrogen. Although they have described a two-dimensional geometry, they showed that the design of an industrial reactor needs the use of a three-dimensional modeling. Recently Phate et al. [14] carried out coupled heat and mass transfer analysis in hydride bed using a commercial code FLUENT 6.2. They considered bulk diffusion for mass transfer in the solid phase and not considered the plateau slope and hysteresis effects of the alloy in their model. It is evident from the literature that both the rates of absorption and desorption are controlled by heat and mass transfer characteristics of hydride bed. Many investigators [1–5,12] attempted to study such characteristics using one-dimensional and two-dimensional models without considering the effects of either convection or radiation. Most of the mathematical models available in literature are alloy dependent [7,10] and do not include the effects of plateau slope and hysteresis of PCT in the Van’t Hoff equation [1,2,4–10,13,14,18]. Further it is clearly observed from the literature [3,11] that the performance of a metal hydride based hydrogen storage system can be.
easily controlled by varying the supply pressure of hydrogen and absorption temperature.

In view of the above, one can conclude that there is a lack of rigorous heat and mass studies on metal hydride based hydrogen storage device at different operating conditions. Further, it is evident from the literature that writing a computer program to solve such a complex coupled heat and mass problem considering the effects of convection, geometrical configuration of the hydride bed, plateau slope and hysteresis of PCT, etc. is tedious and also consumes tremendous time. Recently, Marty et al. [13] and Phate et al. [14] were attempted to solve such coupled heat and mass transfer using FLUENT. However, their models are alloy dependent and do not include the effects of plateau slope and hysteresis effects of the PCT of hydriding alloy. Further, they have not studied the effects of various operating parameters such as supply pressure, absorption temperature, etc. on the hydrogen storage performance of the reactor. In view of the above, the authors made an attempt to use commercial software FLUENT 6.1.22 to solve the above-mentioned problem considering the effects of reactor geometry, plateau slope and hysteresis effects of PCT of the alloy. The present study also aims to predict the optimum operating conditions for storing maximum hydrogen in a given metal hydride reactor.

2. Mathematical model

The configuration of a co-axial cylindrical reactor considered in the present work is shown in Fig. 1. The study is carried out using the thermo-physical properties of indigenously synthesized MnNi$_{4.6}$Al$_{0.4}$ [11]. The inner tube of a cylindrical reactor is a porous filter, which acts as a hydrogen passage and distributor, and prevents the hydride particles from being carried away by the hydrogen gas. The annular space between the filter and the inner concentric tube is filled with MnNi$_{4.6}$Al$_{0.4}$. The heat transfer fluid flows spirally in space between inner and outer concentric tubes. Since the mechanism is assumed to be axisymmetric, only half of the reactor is modeled using the commercial code FLUENT 6.1.22.

2.1. Problem formulation

The governing equations are solved with a fully implicit finite volume numerical scheme embodied in a general purpose code FLUENT 6.1.22. The solution method involves the integration of the governing differential equations over finite control volume and transforming them into a general algebraic form. A transport equation in the general form may be written as

\[
\frac{\partial (\rho \phi)}{\partial t} + \nabla \cdot (\rho u \phi) = \nabla (\Gamma \nabla \phi) + S_h, 
\]

where \(\phi\) is a generic variable that represents the variable solved (i.e., \(u, v, T\)), \(\Gamma\) is the exchange coefficient and \(S_h\) represents the source term. This linearized equation is solved by the Guess and Correct SIMPLE algorithm [15].

The following assumptions are made for simplifying the analysis:

- The gas phase is ideal from the thermodynamic viewpoint.
- The local thermal equilibrium is valid and the radiative heat transfer is negligible. This assumption is valid for all Mm, Zr and Ti based alloys whose operating temperatures are well below 50°C.

The rate of reaction is a function of the bed temperature, hydrogen pressure and hydrogen concentration in the hydride bed. The expression for the reaction kinetics is given by [2,3]

\[
\frac{\partial x}{\partial t} = \pm \sigma \left( \frac{p - p_{eq}}{p_{eq}} \right) (x - x_i) \exp \left( \frac{-E_a}{RT} \right),
\]

where ‘+‘ is for absorption and ‘-‘ is for desorption. ‘x‘ is the hydrogenation fraction defined as the quantity obtained by dividing the mass of hydrogen absorbed by the mass absorbed at the saturation.

The equilibrium pressure \(p_{eq}\) is estimated by using the Van’t Hoff equation [16]:

\[
P_{eq} = \exp \left[ \frac{\Delta S}{R_u} - \frac{\Delta H}{R_u T} + (\varphi_s \pm \varphi_0) \times \tan \left( \pi \left( \frac{x}{x_f} - \frac{1}{2} \right) \right) \right] 10^5 \text{N/m}^2.
\]

The continuity equation includes a sink term to take the amount of hydrogen absorption into account and the resulting equation per unit of volume (kg/m$^3$s) is given by [13]

\[
\frac{\partial \rho_g}{\partial t} + \nabla \cdot (\rho_g \vec{V}) = \Delta \rho (1 - \varepsilon) \frac{dx}{dt},
\]

where gas density \(\rho_g\) is deduced from the perfect gas model and \(\Delta \rho = \rho_{ss} - \rho_s\)

\[
\rho_g = \frac{pM_{H_2}}{R_u T}
\]

and where, the right-hand side term stands for the hydrogen consumption during the hydrogenation.

The energy equation is given by [13]

\[
\rho C_p \frac{\partial T}{\partial t} + (\rho C_p)_g \vec{V} \cdot \nabla T = \lambda \nabla^2 T + \frac{\Delta \rho (1 - \varepsilon) \Delta \Delta H}{M_{H_2}} \frac{dx}{dt},
\]

where

\[
\rho C_p = \varepsilon (\rho C_p)_g + (1 - \varepsilon)(\rho C_p)_m
\]

and

\[
\lambda = \varepsilon \lambda_g + (1 - \varepsilon) \lambda_m.
\]

The source term at the right-hand side of Eq. (2.6) represents the release of heat during the absorption process (W/m$^3$).
2.2. Initial and boundary conditions

Initially, at \( t = 0 \), the temperature, pressure and the hydride density are assumed to be constant within the reactor.

\[
\begin{align*}
\rho_m(Z, r) &= \rho_0, \quad T_m(Z, r) = T_g(Z, r) = T_0, \\
P_g(Z, r) &= P_0. \quad (2.9)
\end{align*}
\]

Along the top surface (Fig. 1) the convective boundary condition is applied.

\[
-\lambda \frac{\partial T}{\partial r}(z, r)_{r=R} = U(T - T_1). \quad (2.10)
\]

Along center line, where \( r = 0 \), the adiabatic conditions give

\[
\frac{\partial P_g}{\partial r}(z, r)_{r=0} = 0, \quad \frac{\partial T}{\partial r}(z, r)_{r=0} = 0. \quad (2.11)
\]

Along the left face, where \( z = 0 \), adiabatic conditions give

\[
\frac{\partial P_g}{\partial z}(z, r)_{z=0} = 0, \quad \frac{\partial T}{\partial z}(z, r)_{z=0} = 0. \quad (2.12)
\]

Along the right face, where \( z = Z \), adiabatic conditions give

\[
\frac{\partial P_g}{\partial z}(z, r)_{z=Z} = 0, \quad \frac{\partial T}{\partial z}(z, r)_{z=Z} = 0. \quad (2.13)
\]

2.3. Modeling of porous region

Porous media are modeled by the addition of a momentum source term to the standard fluid flow equations. The source term is composed of two parts: one is a viscous loss term and other is an inertial loss term (the first and second terms on the right-hand side of Eq. (2.14)).

\[
S_i = -\left( \frac{\mu}{K} v_i + C_2 \frac{1}{2} \rho v_{mag} v_i \right), \quad (2.14)
\]

where \( S_i \) is the source term for the \( i \)th \((x, y \text{ and } z) \) momentum equation, \( K \) denotes the permeability and \( C_2 \) the inertial resistance factor. Since the flow through porous media is assumed to be laminar, the pressure drop is typically proportional to velocity and the constant \( C_2 \) is considered as zero. Ignoring convective acceleration and diffusion, the porous media model reduces to the Darcy law

\[
\nabla p = -\frac{\mu}{K} \vec{v}. \quad (2.15)
\]

The effective thermal conductivity in the porous medium is computed by FLUENT 6.1.22 as the volume average of the fluid conductivity and the solid conductivity. For the transient porous media calculations, the effect of porosity on the time derivative terms is accounted for all scalar transport equations and continuity equation. When the effect of the porosity is taken into account, the time derivative term becomes \( \frac{\partial}{\partial t} (\varepsilon \phi) \), where \( \phi \) denotes the scalar quantity.

2.4. Method of solution

The energy equation employed in FLUENT 6.1.22 has the following form:

\[
\frac{\partial}{\partial t} (\rho h) + \nabla \cdot (\vec{v} \rho h) = \nabla \cdot (\lambda \nabla T) + S_h, \quad (2.16)
\]

where \( h = \text{sensible enthalpy} = \int_{T_0}^{T} C_p dT \) and \( S_h = \text{volumetric heat source} \).

The volumetric heat source term is enabled by incorporating a user-defined function to FLUENT 6.1.22 in the same way the equilibrium pressure equation, the rate of reaction and hydriding fraction equations are enabled. Initially the problem is solved as simple unsteady axi-symmetric heat transfer problem solving only energy equation without the flow equation. Subsequently the flow equation is enabled and user-defined function is complied in FLUENT 6.1.22.
3. Results and discussion

The study of hydrogen absorption in metal hydride bed involves coupled heat and mass transfer process associated with a chemical reaction. The rate of hydrogen absorption in metal hydride depends on many parameters, such as supply pressure, absorption temperature, overall heat transfer coefficient and thickness of the hydride bed. In order to validate the present results with the experimental data, the reactor dimensions and other thermo-physical property of the alloy chosen are taken from Muthukumar et al. [11]. Table 1 shows the dimensions of the reactor, thermo-physical properties of MmNi$_{4.6}$Al$_{0.4}$, properties of hydrogen and constants used in the analysis. Table 2 shows the list of operating and bed parameters, and their ranges considered in the analysis.

The cell independent test has been carried out by analyzing the effect of grid number on the average bed temperature distribution with time, which is illustrated in Fig. 2. A good agreement is observed between $20 \times 200$ and $25 \times 250$. Hence, the present analysis is carried out using a grid size of $20 \times 200$.

3.1. Validation of numerical results

Figs. 3 and 4 show the validation of average bed temperature profiles and rate of hydrogen absorbed with Muthukumar et al. [11] at different supply pressures. The predictions of average bed temperature showed good agreement with the reported experimental data. The prediction values of hydrogen storage capacity showed a slight under prediction at the initial stage and a slight over prediction at the end of absorption. However, the overall agreement was closely matches with the experimental data. This may be due to the assumption of larger void fraction of 0.5 and local thermal equilibrium in the analysis, while in the experiments thermal mass (copper matrix) was used in the void space for the improvement of effective thermal conductivity of the hydride bed.

Table 1
Details of reaction bed geometry, thermo-physical properties of an alloy and constants used in the model

<table>
<thead>
<tr>
<th>Reactor geometry</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the cylinder (Z)</td>
<td>475 mm</td>
</tr>
<tr>
<td>Inner radius of inner cylinder ($r_i$)</td>
<td>4.5 mm</td>
</tr>
<tr>
<td>Inner radius of outer cylinder ($r_o$)</td>
<td>12 mm</td>
</tr>
<tr>
<td>Thickness of cylinder wall</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties of MmNi$<em>{4.6}$Al$</em>{0.4}$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of metal</td>
<td>8400 kg/m$^3$</td>
</tr>
<tr>
<td>Specific heat of metal</td>
<td>419 J/kg K [2,18]</td>
</tr>
<tr>
<td>Effective thermal conductivity of metal (including copper additive)</td>
<td>1.6 W/m K [3,4,18]</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.5</td>
</tr>
<tr>
<td>Effective density of solid at saturation</td>
<td>4259 kg/m$^3$</td>
</tr>
<tr>
<td>Effective density of solid</td>
<td>4200 kg/m$^3$</td>
</tr>
<tr>
<td>Activation energy</td>
<td>21 170 J/mol H$_2$ [3,8]</td>
</tr>
<tr>
<td>$\Delta S$</td>
<td>107.2 J/mol H$_2$-K [17]</td>
</tr>
<tr>
<td>$\Delta H$</td>
<td>28 000 J/mol H$_2$ [17]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties of hydrogen</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity of hydrogen</td>
<td>0.1272 W/m K</td>
</tr>
<tr>
<td>Specific heat hydrogen</td>
<td>14283 J/kg K</td>
</tr>
<tr>
<td>Density of hydrogen</td>
<td>0.0838 kg/m$^3$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Constants used</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal gas constant</td>
<td>8.314 J/mol K</td>
</tr>
<tr>
<td>Reaction constant ($\sigma$)</td>
<td>75 s$^{-1}$</td>
</tr>
<tr>
<td>Slope factor ($\varphi_s$)</td>
<td>0.35</td>
</tr>
<tr>
<td>Constant ($\varphi_o$)</td>
<td>0.15</td>
</tr>
<tr>
<td>Hysteresis factor ($\varphi$)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 2
List of operating and bed parameter ranges

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cold fluid temperature ($T_c$), K</td>
<td>288 ⎼ 293</td>
</tr>
<tr>
<td>2</td>
<td>Overall heat transfer coefficient ($U$), W/m$^2$ K</td>
<td>750 ⎼ 1000</td>
</tr>
<tr>
<td>3</td>
<td>Bed thickness ($r_o - r_i$), mm</td>
<td>5 ⎼ 7.5</td>
</tr>
</tbody>
</table>

Note: 1. Supply pressure is varied from 5 to 35 bar in steps of 5 bar.
2. Numbers in italic bold show the values around which the other parameters are varied.
3.2. Effect of supply pressure on average bed temperature and hydrogen storage capacity

Fig. 5 shows the effect of supply pressure on average bed temperature, which is volume averaged. It is evident from the reaction rate equation (Eq. (2.2)) that the reaction rate depends mainly on the pressure difference between supply and equilibrium pressures \((P_s - P_{eq})\) and hydride bed temperature. During the initial stage of absorption process, the pressure difference is very large, resulting in the rapid absorption. Due to the poor thermal conductivity of the hydride bed, the hydride bed does not transfer the complete heat of absorption released during the initial rapid absorption to the cooling fluid and hence the excess heat is stored in the bed itself. As a result the bed temperature increases rapidly resulting in a sudden rise in the equilibrium pressure, which causes to slow down the absorption rate. As the time progresses, the heat transfer takes place from bed to the cooling fluid, resulting in further hydrogen absorption until the hydride equilibrium pressure becomes equal to the supply pressure. It is observed that rise in the average bed temperature is high at higher supply pressures due to the faster reaction compared to the lower supply pressures. The rate of cooling of the bed is also fast for high supply pressures resulting in an
Fig. 6. Effect of supply pressures on hydrogen storage capacity.

Fig. 7. Variation in average bed temperature at different radial positions.

Fig. 8. Variation in hydrogen concentration at different radial positions.

3.3. Variation in bed temperature and hydride concentration profiles at different radial positions

Fig. 7 reveals that the temperature of the bed decreases continuously from porous filter to convective wall in radial direction. This effect can be explained from the convective effect of the cooling fluid flowing around the bed. The region close to porous filter experiences less heat transfer compared with the region close to the convective wall. Therefore, the amount of heat removal is very rapid from the region close to the convective wall. Due to this reason, the region close to the porous filter experiences high temperature for long time resulting in poorer hydriding rate. It is clear from Eq. (2.3) that the bed temperature strongly influences the hydride equilibrium pressure. Hence at higher equilibrium pressures, the reaction rate decreases due to a low pressure difference ($P_s - P_{eq}$) in the region close to the porous filter. Fig. 8 shows the variation in the hydride concentration along the radial positions and reveals that the rate of hydrogen absorbed in the region close to the convective wall is high due to rapid removal of the reaction heat.

3.4. Effect of cooling fluid temperature on average bed temperature and hydrogen storage capacity

Figs. 9 and 10 illustrate the effect of the cold fluid temperature (absorption temperature) on average bed temperature and amount of hydrogen absorbed. At lower cold fluid temperatures, the temperature difference between hydride bed temperature and cold fluid temperature found to be higher resulting in higher heat transfer rate. At cooling fluid temperatures of below 293 K, the pressure difference is also found to be high leading to a quicker reaction. Hence, due to larger temperature and pressure differences, the hydriding reaction is found to be
rapid below 293 K. Further, due to sloping nature of PCT, low cold fluid temperature also helps in absorbing more amount of hydrogen. Since the PCT characteristics of the alloys at 288, 293 and 298 K are close to each other, the amount of hydrogen stored in all three cases is nearly the same at 20 bar supply pressure. However, the influence of cold fluid temperature is expected to be significant below in supply pressure of 20 bar.

3.5. Effect of overall heat transfer coefficient on bed temperature and hydrogen storage capacity

The overall heat coefficient plays a significant role during both the absorption and desorption of hydrogen. It is observed from Fig. 11 that at overall heat transfer coefficient of 1250 W/m²K, the reaction bed temperature reaches the cooling fluid temperature quickly within 280 s, while for the other two cases it takes nearly about 400 and 500 s, respectively, revealing that an increase in the overall heat transfer coefficient reduces the absorbing time significantly. However, as it is evident from Fig. 12 that the amount of hydrogen absorbed at different overall heat transfer coefficients is the same. Hence, one can conclude that the selection of overall heat transfer coefficient should be based on the available absorption time and supply pressure.
3.6. Effect of bed thickness on hydrogen storage capacity

The thickness of the bed (difference between the outer and inner radii) was varied from 5.0, 7.5, 10.0 and 15.0 mm by keeping the inner radius constant at 4.5 mm. Figs. 13 and 14 together show that the rate at which the hydrogen absorbed in 5.0 mm bed thickness is rapid compared to the other bed thicknesses and also reaches the cooling fluid temperature very quickly accompanied by faster heat transfer rate. It is obvious that higher bed thicknesses offer more resistance in heat transfer resulting in poorer absorption rate.

4. Conclusions

The performance of MmNi$_{4.6}$Al$_{0.4}$ based hydrogen storage device is numerically investigated at different supply pressures, cooling fluid temperatures, overall heat transfer coefficients and bed thicknesses with the help of two-dimensional heat and mass transfer model using FLUENT 6.1.22. The temperature and concentration profiles at different radial positions are reported. The initial hydrogen absorption in the bed occurs very rapidly owing to high pressure difference caused by the supply pressure, resulting in the rapid increase in bed temperature and hydride bed equilibrium pressure. However, the reaction becomes slow with time owing to low heat transfer from the bed to the surrounding cooling fluid due to low poor thermal conductivity of the metal hydride particles, indicating that the total process in the metal hydride bed is controlled by the heat transfer in the bed. In order to decrease the absorption time by increasing the rate of hydriding reaction, the heat and mass transfer aspects of the bed have to be improved. It has been shown that at the supply condition of 30 bar and 298 K, MmNi$_{4.6}$Al$_{0.4}$ stores about 13.1 g of hydrogen per kg of alloy. Increase in overall heat transfer coefficient beyond 1250 W/m$^2$K is not beneficial. The predicted numerical results showed good agreement with the experimental data.

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References


