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TANK DESIGN FOR ON-BOARD HYDROGEN STORAGE IN METAL HYDRIDES

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ABSTRACT

The aim of this work is to reduce the refueling time of a metal hydride storage tank by improving its design, taking in account the total volumetric and mass capacity of the tank.

A heat and mass transfer model is proposed and solved to obtain the charging curve for 1 kg hydrogen in a $LaNi_5$ reference storage tank. Compared to gas transport and reaction kinetics, heat transfer is found to limit the hydrogen charging dynamics of the storage tank. To improve the refueling time, it is found to be necessary to increase first of all the heat transfer inside the metal hydride bed, and subsequently the heat transfer from the metal hydride bed to the cooling fluid.

Technical solutions such as the implementation of aluminum foam and/or internal heat exchanger tubes are investigated. By combining both solutions, the refueling time can be reduced from 400 minutes (reference tank) to 15 minutes. The tank volume still meets the DOE targets, but its mass remains a problem. Therefore, new materials with improved gravimetric capacity have to be developed.

With this work it is now possible to improve the tank design for newly developed storage materials and to evaluate their potential for technical applications.

Keywords: hydrogen, metal hydride, tank design, heat transfer

1. INTRODUCTION

An extensive use of fuel cells in automobiles is only possible with an efficient and safe hydrogen storage technology. An attractive alternative to conventional compressed gas storage and liquid storage is to store hydrogen in solid materials. Many metals and metal alloys are able to store hydrogen reversibly by the formation of a metal hydride, as shown in Eq. (1). The heat released during the absorption of hydrogen in the metal must be removed to allow the reaction to proceed to completion. And reversely, metal hydrides have to be heated to release hydrogen with an adequate rate.

$$M + \frac{x}{2} H_2 \leftrightarrow MH_x + \text{heat} \quad (1)$$

Compared with compressed (CH_2) and liquid (LH_2) storage, the hydrogen storage in metal hydrides (MH_x) offers the advantage of operating at moderate pressure and temperature conditions, being beneficial in regard to safety aspects, in combination with an improved volumetric capacity (Table 1). However, to reach the targets of the Department of Energy (DOE), new materials with significantly improved gravimetric capacity, as well as a reduction of the refueling time are required. This paper deals with the optimization of the hydrogen charging dynamics i.e. with the impact of the metal hydride storage tank design on hydrogen refueling time, taking in account the total volumetric and mass capacity of the tank.

To achieve short refueling times in a metal hydride storage tank, it is first of all necessary to understand the details of the hydrogen charging dynamics in the metal hydride bed. One of the earlier heat and mass transfer models is that of Mayer et al. [1] which expression of reaction rate is still used today. Many authors contributed to the development these models: Sun and Deng [2] focused on the description of heat transfer properties,

Table 1 Hydrogen storage technologies and DOE targets

	DOE 2010	CH_2	LH_2	MH_x
Operation temperature		20°C	-253°C	20°C
Operation pressure		700 bar	1 bar	1 bar
Volumetric density	4.5 kg/100 l	-	+	+
Gravimetric density	6 wt%	+	+	-
Refueling time	<5 min	+	+	-
Loss of useable H_2	<(1g/h)/kgH_2	+	-	+
Safety		-	-	+

NOMENCLATURE

Latin letters

A	van't Hoff constant
B	van't Hoff constant
c_p	specific heat, J/kgK
E_a	activation energy, J/mol
H_2@5	hydrogen amount being absorbed after 5 minutes, kg
K	permeability, m^2
k_a	pre-exponential factor, s^{-1}
M	molecular mass of H_2, kg/mol
$\dot{m}$	reaction rate, kg/m^3s
P	pressure, bar
R	universal gas constant, J/molK
T	temperature, K
u	gas velocity in bed, m/s
U	overall heat transfer coefficient, W/m^2K

Greek symbols

α	volumetric fraction of aluminum in the solid phase
ΔH	reaction heat of formation, J/mol H_2
ε	porosity of the bed
λ	thermal conductivity, W/mK
μ	dynamic viscosity, kg/ms
ρ	bulk density, kg/m^3

Subscripts

0	initial
e	effective
eq	equilibrium
f	fluid
g	gas
s	solid
ss	saturated

Nasrallah and Jemni [3] demonstrated the validity of the local thermal equilibrium and Demircan et al. [4] integrated a momentum balance to express the hydrogen velocity. Based on these works, a mathematical model is developed to describe heat and mass transfer during hydrogen absorption in the metal hydride bed.

A parametric study is carried out with a reference $LaNi_5$ metal hydride storage tank. The hydrogen charging dynamics is found to be mainly limited by the heat transfer in the storage tank. Therefore, two tank designs are investigated: the effective thermal conductivity of the metal hydride bed is improved with aluminum foam and the heat transfer from the bed to the cooling fluid is improved with internal heat exchanger tubes.

Such specific tank designs have already been simulated in the past: Kikkinides et al. [5] proposed a metal hydride reactor with concentric internal and external heat exchangers, Mohan et al. [6] investigated the influence of embedded filters and cooling tubes, MacDonald and Rowe [7] improved the external convection by adding fins on the external face of the tank, and Laurencelle and Goyette [8] simulated the heat transfer in a tank containing aluminum foam.

Compared to the previous works, this paper deals with a systematic study of the influence of two tank designs (with aluminum foam and with internal heat exchanger tubes) and their combination on the hydrogen charging dynamics related to the total volume and mass of the tank. A combined tank design for $LaNi_5$ metal hydride is then proposed to approach the DOE targets in terms of refueling time, as well as volumetric and gravimetric density.

2. MATHEMATICAL MODEL

2.1. Governing equations

The metal hydride bed is considered as a uniform mixture of a solid porous phase (metal hydride) and a gaseous phase (hydrogen). Up-scaling the equations governing heat and mass transfer from pore level to macro level allows considering this discontinuous medium as a continuous one. With the additional assumptions, mass and energy balances in each phase are described below:

- porosity variation during reaction is negligible
- gas phase is considered thermodynamically ideal
- thermo-physical properties of gas and solid are constant
- compression work is negligible
- local thermal equilibrium exists between gas and solid

Mass balance for hydrogen in the solid phase

Variation of the solid density is due to the absorption of hydrogen in the metal hydride at reaction rate $\dot{m}$.

$$(1-\varepsilon)\frac{\partial}{\partial t}\rho_s = \dot{m} \tag{2}$$

Mass balance for hydrogen in the gas phase

Variation of hydrogen density is due to hydrogen flow in the bed at velocity u and simultaneous absorption in the metal hydride at reaction rate m.

$$\varepsilon\frac{\partial}{\partial t}\rho_g = -\nabla\cdot\rho_g u - \dot{m} \tag{3}$$

Gas velocity in the bed can be expressed by Darcy's law (Eq. (4)), with the dynamic viscosity depending on temperature according to Eq. (5) and hydrogen pressure deduced from the ideal gas law (Eq. (6)).

$$u = -\frac{K}{\mu_g}\nabla P \tag{4}$$

$$\mu_g = 9.05e^{-6}\left(\frac{T}{293}\right)^{0.68} \tag{5}$$

$$\rho_g = \frac{PM}{RT} \tag{6}$$

Energy balance

With the assumption of local thermal equilibrium (the temperature of the gaseous phase being the same as in the solid phase), a single energy equation can be written, where the effective volumetric heat capacity and the effective thermal conductivity in the metal hydride bed can be expressed with Eq. (8) and Eq. (9), respectively.

$$(\rho c_p)_e \frac{\partial T}{\partial t} = -\rho_g c_{pg}(\nabla T)u - \nabla\cdot(-\lambda_e \nabla T) - m[\Delta H + T(c_{ps} - c_{pg})] \quad (7)$$

$$(\rho c_p)_e = (1-\varepsilon)\rho_s c_{ps} + \varepsilon \rho_g c_{pg} \quad (8)$$

$$\lambda_e = (1-\varepsilon)\lambda_s + \varepsilon \lambda_g \quad (9)$$

Reaction kinetics:

The hydrogen mass absorbed in the metal hydride per unit of time and unit of volume is given by the reaction rate, which is expressed in Eq. (10), with the equilibrium pressure being calculated from the van't Hoff relationship (Eq. (11)).

$$\dot{m} = k_a \exp\left(\frac{-E_a}{RT}\right)\ln\left(\frac{P}{P_{eq}}\right)(\rho_{ss} - \rho_s)(1-\varepsilon) \quad (10)$$

$$P_{eq} = 1000\exp\left(A - \frac{B}{T}\right) \quad (11)$$

2.2. Reference storage tank

The mathematical model is applied to a 1 kg hydrogen reference storage tank, filled with 72.5 kg $LaNi_5$ powder having a hydrogen storage capacity of 1.38 wt%. The $LaNi_5$ powder is packed in a 17.5 liters cylindrical tank of diameter d = 14.9 cm and length L = 1 m. The hydrogen is supplied from the top of the tank at a temperature of T_0 = 293 K and a pressure of P_0 = 10 bars. The heat generated during absorption is removed from the lateral and the bottom surface by cooling water at a constant temperature of T_f = 293 K (Fig. 1).

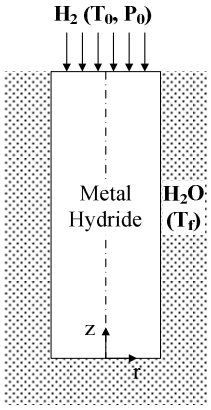

Fig. 1 Schematic of the reference tank

Initially, the temperature, pressure and $LaNi_5$ density are assumed to be uniform in the whole tank:

$$T(t=0) = T_0, \quad P(t=0) = P_0 \quad \text{and} \quad \rho_s(t=0) = \rho_{s0}$$

Boundary conditions are given below.
Due to axial symmetry:

$$\frac{\partial T}{\partial r}(r=0) = 0, \quad \frac{\partial P}{\partial r}(r=0) = 0 \quad \text{and} \quad \frac{\partial \rho_s}{\partial r}(r=0) = 0$$

At the tank inlet:

$$T(z=L) = T_0, \quad P(z=L) = P_0 \quad \text{and} \quad \frac{\partial \rho_s}{\partial z}(z=L) = 0$$

Finally, on the bottom and lateral surfaces, heat transfer is convective and walls are impervious, so that:

$$-\lambda_e \frac{\partial T}{\partial r}(r=R) = -\lambda_e \frac{\partial T}{\partial z}(z=0) = U(T - T_f)$$

$$\frac{\partial P}{\partial r}(r=R) = \frac{\partial P}{\partial z}(z=0) = 0$$

$$\frac{\partial \rho_s}{\partial r}(r=R) = \frac{\partial \rho_s}{\partial z}(z=0) = 0$$

The system of partial differential equations together with the initial and boundary conditions is solved numerically by the finite element method using the commercial software COMSOL Multiphysics®. The grid is refined until the results do not depend on the number of calculation points anymore. Thermo-physical properties of hydrogen and $LaNi_5$ used in these computations are indicated in Table 2.

Table 2 Properties of $LaNi_5$ and hydrogen used in the analysis

Hydrogen	
Specific heat, c_{pg}	14304 J/kgK
Thermal conductivity, λ_g	0.24 W/mK
$LaNi_5$	
Bulk initial density, ρ_{s0}	8280 kg/m^3
Bulk saturated density, ρ_{ss}	8394 kg/m^3
Hydrogen storage capacity	1.38 wt%
Porosity, ε	0.5
Specific heat, c_{ps}	419 J/kgK
Thermal conductivity, λ_s	2.4 W/mK
Overall heat transfer coefficient, U	2500 W/m^{2}K
Permeability, K	10^{-8} m^2
Reaction heat of formation, ΔH	-30780 J/mol H_2
Activation energy, E_a	21179.6 J/mol
Pre-exponential factor, k_a	59.187 s^{-1}
Van't Hoff constant, A	17.738
Van't Hoff constant, B	3704.6

The simulation results in a spatial solution of the evolution of temperature, pressure and $LaNi_5$ density over time. By integrating the density of $LaNi_5$ over the tank volume and scaling it with the storage capacity of $LaNi_5$, the charging curve is obtained, which reflects the mass of hydrogen absorbed in the tank as a function of time (Fig. 2). The complete refueling time for the 1 kg hydrogen reference storage tank is found to be about 400 minutes, corresponding to 212 g hydrogen being absorbed in the tank within the 5 minutes allowed by the DOE targets.

3. PARAMETRIC STUDY

To reduce the hydrogen refueling time of the reference $LaNi_5$ storage tank, it is first of all necessary to determine the details of its charging dynamics. A parametric study is thus performed to investigate the effect of gas transport, reaction kinetics and heat transfer for the 1 kg hydrogen $LaNi_5$ metal hydride reference storage tank described above. The hydrogen amount being absorbed in the tank after the 5 minutes recommended by the DOE targets, H_2@5, is taken in the following as the performance criteria.

3.1. Influence of gas transport

To investigate the influence of gas transport in the reference storage tank, simulations are performed by varying the permeability between 10^{-18} and 10^{-6} m^2. The hydrogen amount being absorbed in the reference tank after 5 minutes is reported as a function of permeability in Fig. 3.

Increasing the permeability of the metal hydride bed leads to an increase in hydrogen being absorbed in the tank, but is limited to a maximum of 212 g after 5 minutes, which is achieved for permeability higher than 10^{-11} m^2. According to literature [1-4], a permeability of 10^{-8} m^2 is a typical value for a $LaNi_5$ bed. Therefore, for this permeability, gas transport does not limit the hydrogen charging dynamics of the reference storage tank.

3.2. Influence of reaction kinetics

Simulations with activation energy varying between 10 and 40 kJ/mol and pre-exponential factor varying between 1 and 10000 s^{-1} are performed to investigate the influence of reaction kinetics on the charging dynamics of the reference storage tank. The corresponding amount of hydrogen absorbed after 5 minutes is reported in Fig. 4.

As expected, the hydrogen amount H_2@5 is higher with better kinetics, corresponding to higher pre-exponential factor and lower activation energy. But, as for the permeability, the limit of about 220 g of absorbed hydrogen can not be overcome. Again, activation energy of 21179.6 J/mol and pre-exponential factor of 59.187 s^{-1} used in the simulation of the reference storage tank already result in the maximum hydrogen amount. Therefore, for this activation energy and this pre-exponential factor, reaction kinetics does not limit the hydrogen charging dynamics of the reference storage tank.

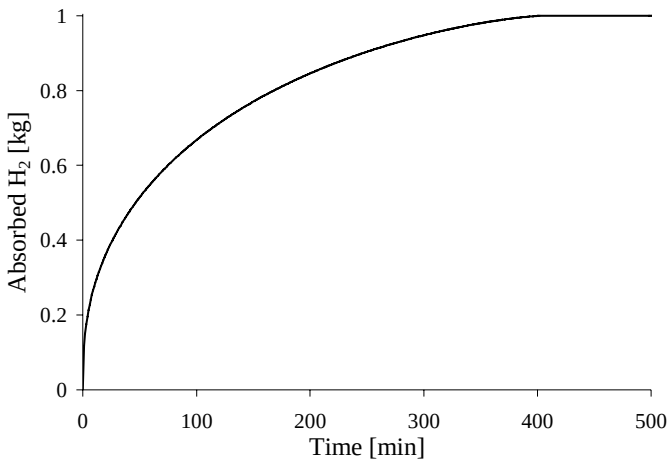

Fig. 2 Charging curve of the reference storage tank

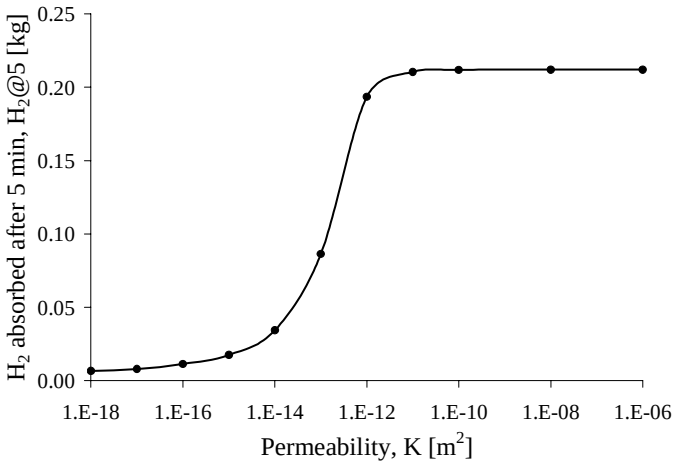

Fig. 3 Influence of gas transport

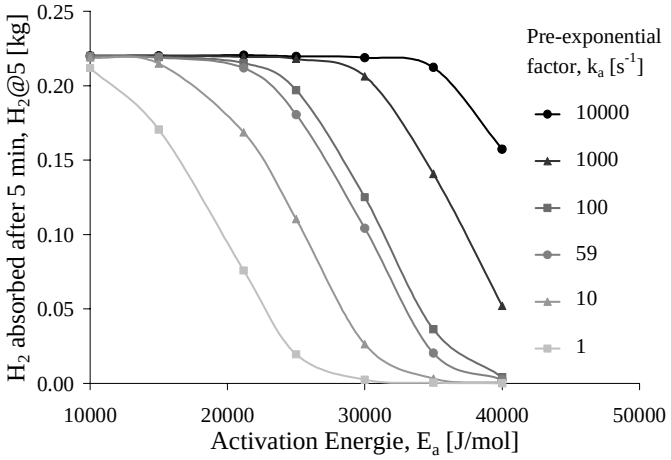

Fig. 4 Influence of reaction kinetics

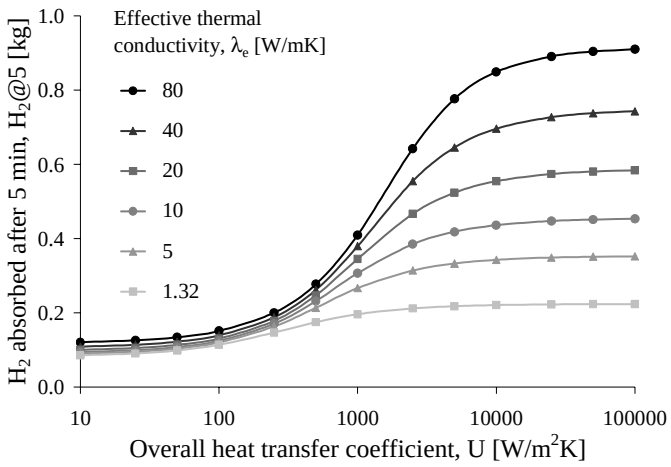

Fig. 5 Influence of heat transfer

3.3. Influence of heat transfer

The third influence to be investigated is the heat transfer inside the metal hydride bed and from the bed to the cooling fluid. The effective thermal conductivity of the metal hydride bed λ_e is varied between 1.32 and 80 W/mK and the overall heat transfer coefficient from the bed to the cooling fluid U between 10 and 100000 W/m^{2}K. The calculated amount of hydrogen absorbed after 5 minutes is displayed in Fig. 5.

In the case of the reference storage tank, simulation is performed for an effective thermal conductivity of 1.32 W/mK and an overall heat transfer coefficient of 2500 W/m^{2}K. This leads to an amount of 212 g hydrogen being absorbed in the tank after 5 minutes. For such low values of the effective thermal conductivity within the bed, an improved overall heat transfer coefficient does not have a large impact on the hydrogen amount H_2@5. In fact, the effective thermal conductivity of the metal hydride bed has to be enhanced before a positive effect can be achieved by an increase of the overall heat transfer coefficient. With such an optimized configuration, it is possible to charge more than 900 g of hydrogen in the tank within the 5 minutes recommended by the DOE targets.

It can thus be concluded that heat transfer limits the hydrogen charging dynamics in the reference storage tank. In fact, the effective thermal conductivity inside the metal hydride bed limits first of all the amount of hydrogen being absorbed in the tank after 5 minutes. For improved internal heat transfer with high effective thermal conductivities, the heat transfer from the bed to the cooling fluid limits subsequently the hydrogen charging dynamics and has to be improved too, in order to decrease refueling times in the hydrogen storage tank.

4. DESIGN OPTIMIZATION

Technical solutions to improve the heat transfer inside the metal hydride bed and from the bed to the cooling fluid are investigated (Fig. 6). On one hand, it is a possibility to add highly conductive materials inside the tank to improve the effective

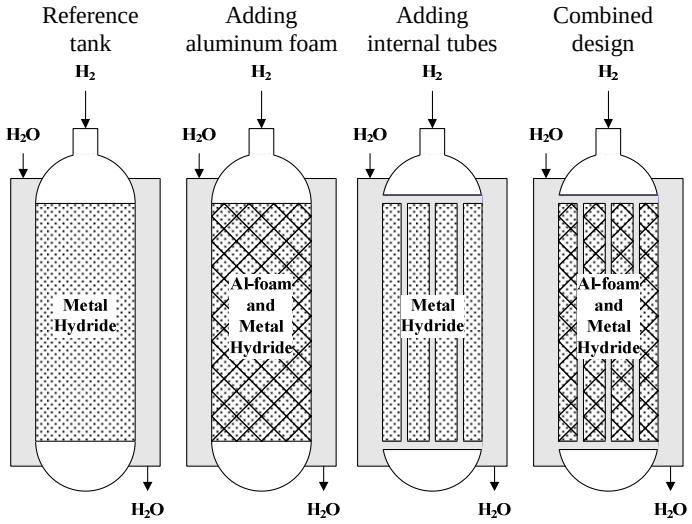

Fig. 6 Design solutions to increase the heat transfer

conductivity of the bed. Hence, simulations with aluminum foam, as a relatively light metal (2700 kg/m^3) with high conductivity (237 W/mK) are performed. On the other hand, to improve the heat transfer from the bed to the cooling fluid, the surface area between the bed and the cooling fluid is increased. The addition of heat exchanger tubes inside the metal hydride storage tank is thus investigated, too.

For these two designs plus their combination, the amount of hydrogen being absorbed after 5 minutes is calculated with the previously given mathematical model. At the same time, the consequences of these new designs on the total mass and volume of the storage tank are analyzed.

4.1. Influence of aluminum foam

Firstly, the addition of aluminum foam in the metal hydride bed is investigated. Based on the results from the parametric study, it is expected that the amount of hydrogen H_2@5 increases with the effective thermal conductivity of the bed, i.e. with the aluminum fraction. Additionally, adding a chemically inert material in the metal hydride bed reduces the heat produced per unit of volume, which is also beneficial for better hydrogen charging dynamics. However, higher tank volumes result in longer heat transfer paths, which can inhibit the hydrogen refueling process.

Simulations are performed for volumetric fractions of aluminum α, varying between 0.1 and 0.9. The aluminum fraction is implemented in the mathematical model by describing the volume V of the tank as follows:

$$V = \varepsilon V + (1-\varepsilon)(1-\alpha)V + (1-\varepsilon)\alpha V \qquad (12)$$

with εV being the gas phase, $(1-\varepsilon)(1-\alpha)$ being the $LaNi_5$ phase, and $(1-\varepsilon)\alpha$ being the aluminum phase. Effective thermal conductivity λ_e and effective volumetric heat capacity $(\rho c_p)_e$ of the bed are calculated using Eq. (12). Simulation results are reported in Fig. 7.

The amount of hydrogen being absorbed after 5 minutes is found to increase with aluminum fraction. Compared with only a variation of the effective thermal conductivity of the metal hydride bed (Fig. 5), adding aluminum foam results in better performances. Hence, the reduction of the heat produced per unit volume overcomes the increase of the heat transfer paths.

Concerning the volume and the total mass of the tank, a drastic increase with rising aluminum fraction can be observed. Aluminum fractions above 0.6 lead to unrealistic tank mass. The maximum volume allowed by DOE (23 liters) is reached for an aluminum fraction of 0.24, which therefore is set as the upper limit for technical applications.

4.2. Influence of internal heat exchanger tubes

Adding heat exchanger tubes inside the tank leads to an increase of the heat exchange area between the metal hydride bed and the cooling fluid. As long as the effective thermal conductivity of the bed is low, the heat transfer from the bed to the cooling fluid does not limit the hydrogen charging dynamics. Consequently, it can not be expected to improve the charging dynamics by only increasing the heat exchanger area. However, adding internal tubes also reduces the heat transfer paths in the metal hydride bed, which can lead to a better hydrogen charging dynamics.

Simulation results for the number of heat exchanger tubes varying from 1 to 9 are displayed in Fig. 8 (for better comparability, the same scale as for Fig. 7 is used). The tubes have 1 cm radius and 1 m length and are arranged in circles. As expected, the amount of hydrogen H_2@5 increases steadily with the number of internal tubes. With each tube having a mass of about 1.3 kg and a volume of 0.31 liters, the addition of up to 9 tubes is not critical in regard to the volume and the total mass of the tank. However, with 9 tubes, only 400 g of hydrogen are charged in the tank after 5 minutes. Therefore, the use of internal heat exchanger tubes which only help to reduce the heat transfer paths can not be alone a technical solution for improved hydrogen charging dynamics.

4.3. Combined design

A promising solution to improve hydrogen charging dynamics is to combine both of the previous designs. In agreement with the parametric study, the addition of aluminum foam is found to have a higher impact than the addition of internal heat exchanger tubes. That is why a maximal fraction of aluminum is packed inside the tank with the upper volume limit of 23 liters, and the remaining volume is filled with heat exchanger tubes. The maximal volume of 23 liters is reached for an aluminum fraction of 0.24. Hence, an aluminum fraction of 0.2 is used (corresponding to a tank volume of 21.9 liters) and the residual volume is filled with 3 internal tubes.

The charging curve of this combined design tank as well as charging curves of the reference tank, the tank with 3 heat exchanger tubes and the tank containing a 0.2 aluminum fraction are plotted in Fig. 9. Compared to the reference tank, the combined design tank reduces the refueling time from 400 minutes

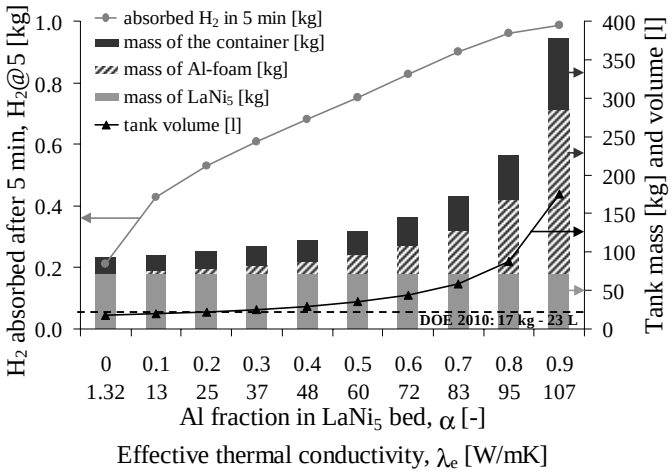

Fig. 7 Influence of aluminum foam

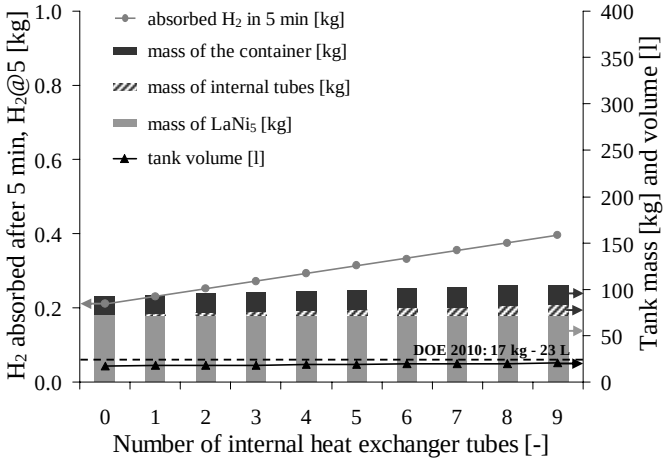

Fig. 8 Influence of internal heat exchanger tubes

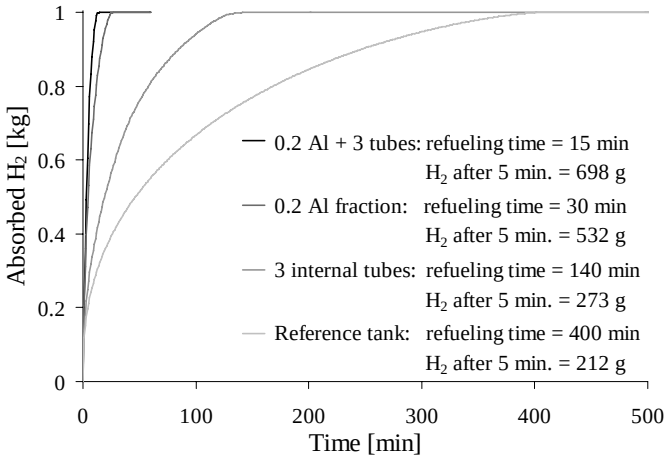

Fig. 9 Charging curves for different design solutions

Table 3 Performances summary for the investigated design configurations

	Reference tank	3 internal heat exchanger tubes	0.2 aluminum fraction (vol.)	Combined design…	*…with new material*	DOE 2010
Mass of H_2	1 kg	1 kg	1 kg	1 kg	*1 kg*	1 kg
Mass of $LaNi_5$	72.5 kg	72.5 kg	72.5 kg	72.5 kg		
*Mass of new material**					*20 kg*	
Mass of Al-foam			6 kg	6 kg	*6 kg*	
Mass of internal tubes		3.8 kg		4.1 kg	*4 kg*	
Mass of the container	20.1 kg	20.6 kg	23.3 kg	23.9 kg	*24 kg*	
Total mass of the tank	92.6 kg	96.9 kg	101.8 kg	106.5 kg	*54 kg*	17 kg
Total volume of the tank	17.5 l	18.4 l	21.9 l	22.9 l	*23 l*	23 l
Refueling time	400 min	140 min	30 min	15 min	*15 min*	5 min
Absorbed H_2 in 5 min.	212 g	273 g	532 g	698 g	*700 g*	1 kg

** hydrogen storage capacity: 5 wt%, bed density: 1143 kg/m^3, same λ_e, U, K, k_a, E_a as $LaNi_5$*

to 15 minutes, and increases the amount of hydrogen being charged in the tank after 5 minutes from 212 g to 698 g.

If an adding of 3 heat exchanger tubes to the reference design does not significantly increase the amount of hydrogen in the tank after 5 minutes, a large increase is observed when adding these 3 tubes in the tank already filled with 0.2 aluminum fraction. According to the parametric study, the heat transfer from the metal hydride bed to the cooling water only limits the hydrogen charging dynamics when the effective heat transfer in the bed is improved.

The combined design tank leads in better performances than adding only internal heat exchanger tubes or only aluminum foam. On the other hand, it additionally allows for saving aluminum foam. In fact, the combined design tank with 3 tubes and 0.2 aluminum foam has equivalent amount of hydrogen being absorbed after 5 minutes than the tank with 0.4 aluminum foam (Fig. 7), but it results in much lower volume and mass of the tank, due to the aluminum save. A combination between the addition of internal heat exchanger tubes and aluminum foam is therefore the most potential technical solution to reduce the refueling time of the tank.

4.4. Developing new materials

An overview of the different design configurations being investigated is displayed in Table 3. The mass and volume of the tank are detailed as well as its performance regarding hydrogen charging dynamics in term of refueling time and amount of hydrogen absorbed in the tank after 5 minutes. For each configuration, the volume of the tank meets the DOE targets but its mass largely exceeds it. Most of the tank mass is due to the $LaNi_5$ metal hydride. It is thus necessary to develop new materials with improved hydrogen storage gravimetric capacity.

A performance calculation of the combined design tank filled with a material having a 5 wt% hydrogen storage capacity and a bed density of 1143 kg/m^3 is included in Table 3. When this new material has at least equivalent permeability, reaction kinetics and heat transfer properties, it takes the same refueling time as for the combined design filled with $LaNi_5$. The volume of the tank is not changed, but the total mass of the tank is then divided by two. Furthermore, for a material having a bed density equivalent to the one of $LaNi_5$ (4140 kg/m^3), the volume of the tank is accordingly reduced. This leads to a reduction of the heat transfer paths, which improves the hydrogen charging dynamics and results in shorted refueling times.

To reach the DOE targets it is therefore not only important to develop new materials with high hydrogen storage gravimetric capacity, but these materials should have at least equivalent permeability, reaction kinetics and heat transfer properties like $LaNi_5$, and finally, sufficient bed density. For such materials, it is then possible to develop a combined tank design with aluminum foam and heat exchanger tubes to reduce the refueling time of the hydrogen storage tank, with minimal impact on its volume and total mass.

5. CONCLUSION

A mathematical model describing heat and mass transfer during hydrogen absorption in a $LaNi_5$ metal hydride bed is proposed and solved to obtain the charging curve of a reference storage tank containing 1 kg hydrogen.

According to the parametric study, it is found that first of all the effective thermal conductivity of the metal hydride bed and secondly the overall heat transfer from the metal hydride bed to the cooling fluid limit the hydrogen charging dynamics of the storage tank.

Various design configurations with improved heat transfer such as adding aluminum foam and adding heat exchanger tubes are thus investigated. This leads to a combined tank design containing 0.2 volumetric fraction of aluminum and 3 internal heat exchanger tubes. This combined design tank reduces the refueling time from 400 minutes (in comparison to the reference tank) to 15 minutes. If the tank volume is in accordance with the DOE targets (23 liters), its very high mass (106.5 kg) is still a critical problem that has to be overcome.

Developing new materials with improved gravimetric capacity is a necessary step to improve the gravimetric density

of metal hydride tanks. However, depending on their bed density, permeability, reaction kinetics and heat transfer properties, the tank design have to be improved to reduce the refueling time of the hydrogen, with minimal impact on the volume and total mass of the tank.

The present work can consequently be used as a new tool to compare and estimate the potential of promising laboratory sorption materials on the automotive tank scale.

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