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Next Generation Car – Coupled Thermochemical Reactions for Preheating Vehicle Components

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Summary

The German Aerospace Center has merged a wide range of technological research and development for future cars in a project called "Next Generation Car". Within this project, thermal energy storage for improving the efficiency in future vehicles is investigated. This work focuses on thermochemical energy storage able to produce heat even at low ambient temperatures (-20 … +20°C). This heat can be used to preheat the battery for higher electrical power and less degradation. Based on the absorption and desorption of hydrogen between two metal hydrides, the storage is able to produce heat from ambient temperature. Although metal hydrides can react fast even at low temperatures, no experimental data of coupled metal hydride reactions below freezing point and at relevant scale is available in literature. For the development of thermochemical energy storages in future vehicle concepts with high thermal output powers, experimental investigations regarding the main influence factors are needed. Therefore, an experimental test rig of coupled metal hydrides was built and tested at vehicle boundary conditions. Charging by low level thermal energy (130°C), the results showed high thermal power outputs even at low discharging ambient temperatures. The variation of the ambient temperature showed a significant influence on the thermal power. The values ranged from 0.6 kW/kg_{MH} at -20°C up to 1.6 kW/kg_{MH} at +20°C. These are the highest values reported in literature so far.

Keywords: demonstration, energy, energy storage, hydrogen, power density, research, thermal management,

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1 Introduction

The project Next Generation Car (NGC) is a large scale project developing new electrical vehicles concepts and the related technologies. The project covers six research and development domains: the overall vehicle concepts, the lightweight body design, advanced powertrain, efficient energy management, mechatronic chassis and vehicle intelligence. The project has a holistic approach focusing on integrated development of technologies, methods and tools for future cars.

With little heat available in battery electric vehicles, the demand of heat can be covered by thermal energy storages. These are investigates within the NGC project to cover heat demands in future vehicles. The investigated concepts include high temperature sensible energy storages based on solid media with an integrated power-to-heat option to allow high storage densities and latent energy storage based on metallic Phase Change Materials (mPCM), which absorb heat during a solid-liquid phase change at a constant temperature level, additionally to the use of sensible heat. See more details in [1].

Focus of the work presented here is on thermochemical energy storage which stores the reaction heat of a solid/gas reaction.

This principle provides the following advantages:

- Heat can be stored free of loss as long as required at ambient temperature (thermal energy is stored as chemical potential) by preventing the reaction by separating the reaction partners
- Thermal energy is produced on demand from ambient temperature by recombining the reaction partners, e.g. by opening a valve
- High thermal energy densities can be achieved due to high reaction enthalpies even at low charging temperatures (130°C was considered), such as waste heat or building heat

Preconditioning in electric vehicles, e.g. the battery, can have the benefit of higher electrical power and less degradation. The vehicle boundary conditions require the thermal energy storage to discharge within a few minutes at ambient temperatures between -20 and +20 °C, which is very challenging for sorption systems. Thus the focus of investigation is the maximum thermal power that can be reached for the considered application. Until now, only little work exists in literature regarding thermochemical reactions with high thermal power at low temperatures (see e.g. [2]). Metal alloys forming hydrides with hydrogen are assumed to have fast reaction kinetics; nonetheless little characteristic data exists in literature at these boundary conditions, especially at these low temperature levels (see e.g. [3], [4]). In particular, experimental data of coupled metal hydride reactions below freezing point and at relevant scale is not available in literature.

Therefore, the objective of this work is the experimental investigation of thermal power of coupled metal hydrides at vehicle boundary conditions and the influence of the ambient temperature. For more detail, see also [5].

2 Experimental section

This section provides details about the operation principle of a closed metal hydride thermal energy storage, the materials used, and the test rig and boundary conditions investigated as well as the achieved thermal power and main influence factors.

2.1 Operation principle of a closed metal hydride thermal energy storage

Metal alloys can form metal hydrides with hydrogen based on a reversible gas/solid reaction. This equilibrium reaction requires and releases heat which can be describes with

$$MH_{x+y} + \Delta H \leftrightharpoons MH_x + \frac{y}{2} H_2 \text{ (1).}$$

The temperature level at which the hydrogen is absorbed or desorbed depends on the pressure level of the hydrogen and vice versa. This relationship can be illustrated in a Van’t Hoff-plot, see Figure 1, depicting the thermodynamic interaction between two different metal hydrides in a closed system.

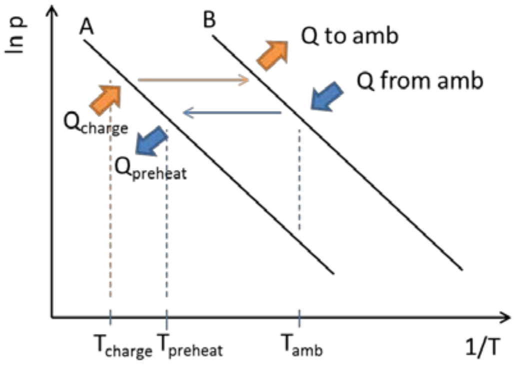

Figure 1. Van’t Hoff plot of two different metal hydrides A and B.

The different materials are connected by a gas tube and can be separated by a valve. In the charged state of the thermal energy storage, metal hydride B (MH_B) contains much hydrogen whereas metal hydride A (MH_A) contains only little hydrogen. Both are at ambient temperature, therefore the pressure of MH_B is higher than in MH_A. Once the valve is opened for discharging (indicated in blue in Figure 1), hydrogen flows from MH_B to MH_A leading to desorption of more hydrogen in MH_B which requires heat from the ambient and absorption of hydrogen in MH_A which releases heat. The temperature of the released heat in MH_A rises according to its equilibrium properties to the level of the preheating temperature. The storage is charged (indicated in orange in Figure 1), with heat at charging temperature level, e.g. from electricity when the electric vehicle is charging, which is supplied to MH_A. The pressure rises according to the characteristics given in Figure 2 and exceeds the pressure level in MH_B at ambient temperature. Now the valve is opened and hydrogen flows back into MH_B. The absorption heat is released to the ambient. After regeneration, the valve is closed and the energy is stored free of losses until it is needed again.

Such a closed thermochemical energy storage does not require or release hydrogen. The operation pressure depends on the chosen materials and was below 10 bar in this work. Also, no insulation is required for these storages.

2.2 Boundary conditions and material selection

The following boundary conditions in vehicles were considered:

- $T_{ambient}$ = -20 … +20°C
- T_{charge} = 130°C

The considered charging temperature level might be made available by waste heat of vehicle components such as power electronics or battery in electric vehicles or by an internal combustion engine in conventional vehicles. If electricity can be used, the charging temperature level increases, leading to even higher temperature levels of the released heat than shown in this study. The chosen materials are $LaNi_{4.85}Al_{0.15}$ [6] as heat producing material and Hydralloy C5 [7] as hydrogen storage material.

2.3 Test rig

A test bench was developed and high thermal power tube bundle reactors were filled with 960 g of $LaNi_{4.85}Al_{0.15}$ as heat producing material and 615 g of Hydralloy C5 as hydrogen storage material as shown in Figure 4.

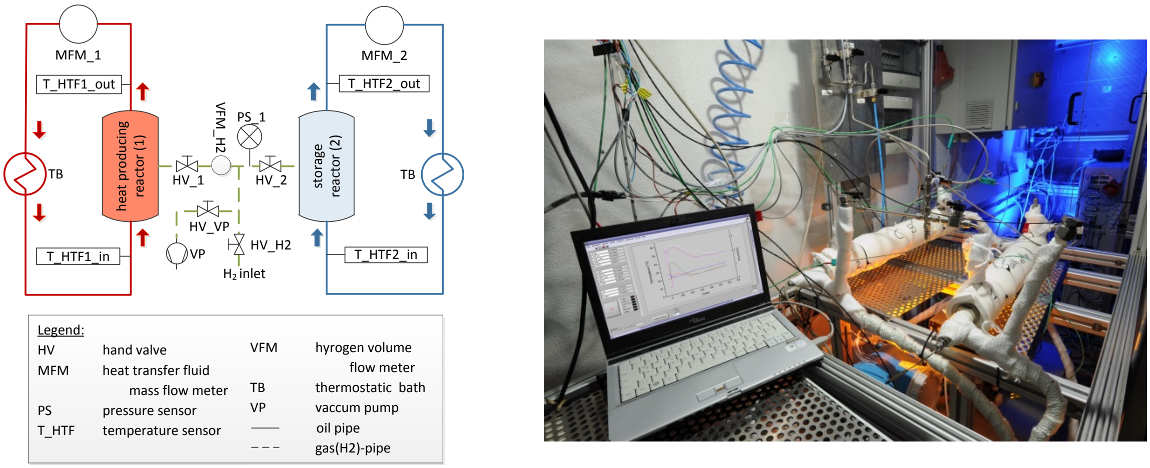

Figure 2. Layout (left) and picture (right) of test bench and the reactors.

The test rig can provide the assumed ambient and charging temperatures and monitor the results. The thermal power is measured in the heat transfer fluid (HTF), therefore taking all thermal masses and heat transfer losses into account. The mass flow of the HTF was set to 250 kg/h. Knowing the mass flow and heat capacity of the HTF and the temperature in front of and behind the reactor at all time, the thermal power in kW over time can be calculated by

$$P = \dot{m}_{HTF}\, c_{p,HTF}\, (T_{HTF,out} - T_{HTF,in}) \text{ (2).}$$

The specific thermal power in kW/kg$_{MH}$ is calculated by dividing the power by the mass of the metal hydride in the reactor.

The impact of the ambient temperature was investigated.

2.4 Results

The ambient temperature was varied between -20 and +20°C. The thermal power is given in Figure 5.

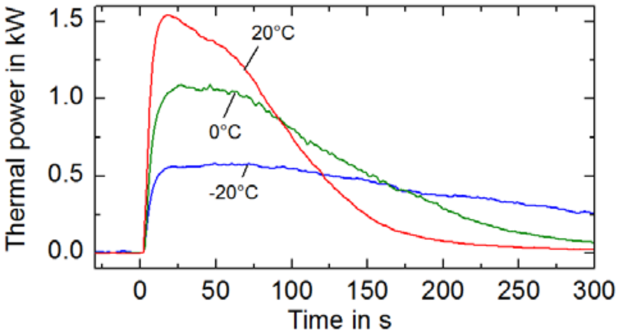

Figure 3. Thermal power over time at different ambient temperatures.

Besides high thermal power values, a large influence of the ambient temperature can be seen from Figure 3. The peak thermal power increases from 0.6 kW/kg$_{MH}$ at -20°C to 1.16 kW/kg$_{MH}$ at 0°C up to 1.6 kW/kg$_{MH}$ at 20°C. The temperature of the HTF increases by 5 K at -20°C and 12 K at 20°C.

This large influence of the ambient temperature might either be due to decreasing reaction kinetics of the material or due to increasing pressure losses at lower operation pressure. Knowing the cause by further investigation, the design can be improved in order to increase the thermal power at lower temperatures. More results will be presented at the EVS30 conference and are also given in [5].

3 Conclusion

Metal hydrides in a closed system were investigated as thermochemical energy storages for battery electric vehicles. $LaNi_{4.85}Al_{0.15}$ was used for the heat producing side and Hydralloy C5 was used for the hydrogen storage side. The ambient temperature shows a large influence on the thermal power. The achieved thermal power of 0.6 kW/kg$_{MH}$ at -20°C up to 1.6 kW/kg$_{MH}$ at +20°C present the highest values in literature so far.

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Authors

Mila Dieterich finished her study of environmental engineering in Stuttgart, Germany, in 2012 with a thesis about simulation of a thermochemical energy storage in technical scale for concentrating solar power plants. Since then she works at the Institute of Engineering Thermodynamics at the German Aerospace Center (DLR) in Stuttgart on gas/solid reactions. Currently she is preparing her thesis considering metal hydrides for the application in vehicles, focusing on the influence factors at low temperature.