Reversible Solid State Hydrogen Storage System Integrated with PEM Fuel Cell

V.I. Borzenko, D.V. Blinov, D.O. Dunikov, S.P. Malyshenko

This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 4: Storage Systems / Policy Perspectives, Initiatives and Co-operations
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-4
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-654-5

Reversible Solid State Hydrogen Storage System Integrated with PEM Fuel Cell

V.I. Borzenko, **D.V. Blinov**, **D.O. Dunikov**, **S.P. Malyshenko**, Joint Institute for High Temperatures RAS, Russia

Abstract

The results of International IPHE Project "Reversible Solid State Hydrogen Storage and Purification System for FC Power Supply" are presented. The project focused on the thermal and integration aspects of metal hydride technology of hydrogen storage and purification. The experimental part of the project included various system –scale metal hydride devices for purification and storage tests. Basing on the results of mathematical modeling, the optimized from the heat and mass transfer point of view low temperature metal hydride (AB_5 type) devices for the purification system were created and tested within the fully automatic purification system with capacity of 3000 st.l/hour. The test results of the 100 kg alloy hydrogen storage device integration with PEM FC also presented. It was shown experimentally, that, taking into account overall energy balance of the integrated system, it is possible to increase the total efficiency of the PEM FC based power supply system with low temperature traditional metal hydride storage. The ways for metal hydride units thermal performance improvement and capacity increase for different cases of the technology application are also presented and discussed.

1 Introduction

The basic barriers of metal-hydride hydrogen storage and purification technology are the following [1,2]**:**

- low weight capacity of hydrogen absorbing materials;
- low effective thermal conductivity of hydrogen absorbing materials beds;
- negative impurity influence on sorption process;
- the lack of knowledge of system effects at the integration of solid-state hydrogen storage systems and fuel cells.

In spite of the above mentioned disadvantages of traditional low temperature metal hydrides (wt. capacity <2%), the stationary applications on their base can find their niche at the market for example in back-up power, hydrogen purification for turbo generator cooling systems, energy accumulation for power production using renewable energy and others [3]. The transition from laboratory scale amounts of hydrogen absorbing materials and experimental MeH devices to system scale demands concentration on design optimization from the point of view of better heat transfer and system integration.

2 Optimized Hydrogen Absorbing Materials

New, low temperature AB_5 type alloys were manufactured in cooperation with Moscow State University [3] both for hydrogen storage and purification subsystems with respect to the requirements of MeH storage and purification system and the requirements of commercial 5 kW PEM FC for initial pressure and hydrogen purity.

3 Experimental Apparatus

Complex test facility for investigations of heat and mass transfer peculiarities at hydrogen sorption in MeH devices of reactor and system scales was created at H2Lab [3], JIHT RAS, which included hydrogen preliminary purification subsystem (de-oxygenizer and dryer), experimental MeH hydrogen fine purification subsystem (5 kg of AB_5 alloy reactors, Figure 1), hydrogen storage subsystem (81 kg of AB_5 alloy single reactor, Figure 2) and commercial GenCore 5T (PlugPower) PEM fuel cell.

Type 1. **Type 2.** **Type 3.**

Figure 1: AB_5 (5kg) alloy hydrogen storage and purification reactors: Type 1 – cartridge type, Type 2, 3 – tube and shell type.

Figure 2: Tube-and-shell type hydrogen storage device, combined air and liquid cooling/ heating, 81 kg of AB_5 alloy.

4 Calculation Model

Mathematical model, created in cooperation with Moscow Power Engineering Institute [4-6], includes a set of 3D Navier-Stokes unsteady equations of mass and energy conservation for solid and gas and momentum equation for gas.

The main assumptions taken for the calculations are the following:

- Gaseous phase is homogeneous mixture of *N* components, one of which is hydrogen;
- Solid phase includes impermeable structures (unit walls), permeable “passive” structures (internal tube with porous wall), permeable “active” structures (layers of intermetallic particles);
- The gaseous phase is ideal from the thermodynamic viewpoint;
- Specific isobaric heat capacity of gas mixture components is constant;
- The viscous dissipation and compression work are negligible.

Closing equations: interface interaction, absorption/desorption kinetics, effective permeability and coefficient of effective thermal conductivity

5 Results of Calculation and Modeling

The qualitative correspondence of the experimental and calculation results (Figure 3.) gave good background for the optimization of real geometry of MeH reactors. The proposed heat exchanger types ranged from separate cartridge (Type 1) to tube-and-shell (Type 2,3) with two side cooling and heating.

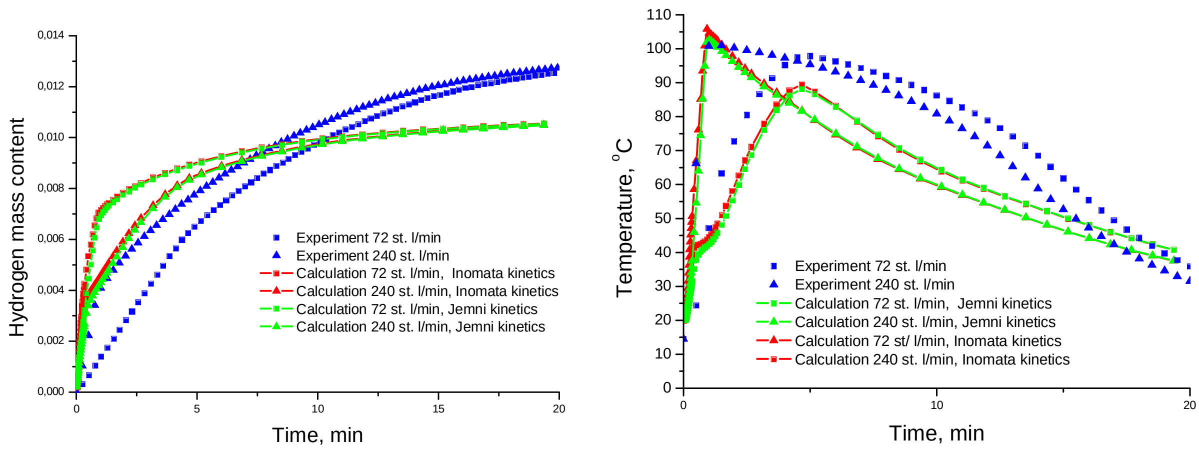

Figure 3: Hydrogen sorption in Type 1 reactor, verification of kinetics, constant hydrogen flow.

The problem of calculations and measurements correspondence can be solved by reliable PCT measurement and also by taking into account the scaling effect at transition from lab-scale to reactor-scale amounts of hydrogen absorbing materials.

6 Integration Results

Commercial GenCore 5B(T)48 Fuel Cell system was successfully supplied with hydrogen for nearly 4 hours with total hydrogen volume of up to 13 st. m^3 (Figure 4,5). The resources of low potential heat (FC coolant) cover the storage tank desorption needs, i.e thermal integration is possible.

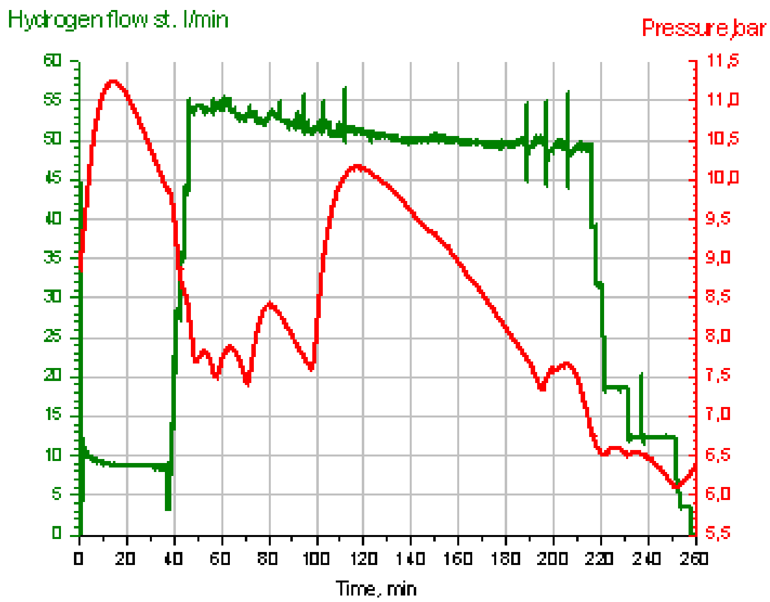

Figure 4: Operation of hydrogen storage device at FC supply.

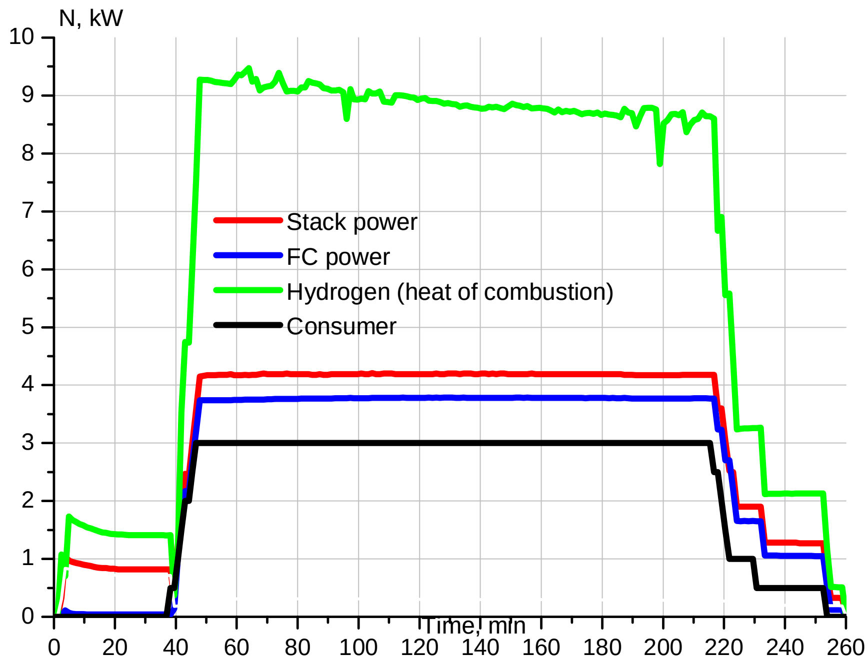

Figure 5: Energy parameters at operation of FC supplied by MeH hydrogen storage unit.

7 Purification

The approach to MeH fine purification is based on the useful feature of metal hydrides to selectively absorb hydrogen from the hydrogen containing gas. With this, the problem of metal hydride poisoning is very critical and must be solved according to the specific application. The investigations of purification in our experiments were carried out using inert gas admixtures and using low-cost technical hydrogen.

PSA-like mode for fine purification was proposed basing on the results of the experiments on MeH purification subsystem using reactors of Type 3. The essence of the operation mode is periodic admixture evacuation from the spare volume of MeH reactor which can be done in various ways, depending on the optimization target function (deeper purification or hydrogen saving): constant duration, constant final pressure and constant amount of gas. For the further development of the purification subsystem “constant lower pressure (atmospheric)” mode was selected (Figure 6.).

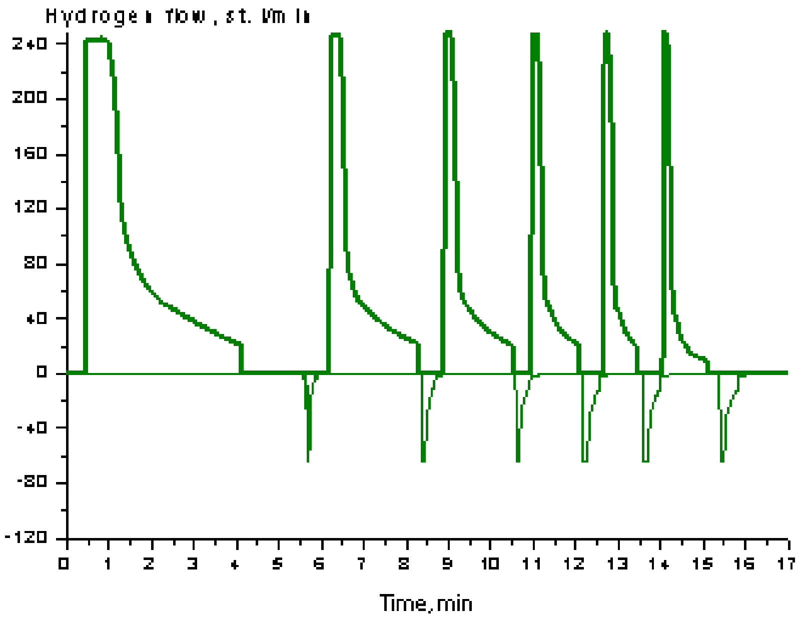

Figure 6: MeH reactor charging at PSA-like mode with admixture (3% inert gas) evacuation down to atmospheric pressure in the spare volume of the reactor.

The losses of hydrogen at this operation mode can reach 23% of the total flow, however other modes fail to provide the purity required by FC (99.95%).

8 Conclusions and Acknowledgements

The peculiarities of heat and mass transfer processes in fine-dispersed porous beds of solid hydrogen absorbing materials were studied both theoretically by modeling and experimentally in model reactor.

Reactor optimization on the base of developed 3D heat and mass transfer model was carried out and new types of reactors with enhanced thermal characteristics were created.

The feature of selective hydrogen sorption from hydrogen containing gas admixture was used for the creation of metal-hydride purification system for use in variable applications , PSA-like mode of purification was proposed and verified experimentally.

The ways for MeH storage and purification units integration with PEM FC were studied and the opportunity for overall efficiency of the fuel supply system was shown.

The possibility of system-scale utilization of traditional low temperature metal hydrides (AB_5) in power production units was experimentally proved.

The research was carried out as a part of the IPHE International Project "Reversible Solid State Hydrogen Storage and Purification System for FC Power Supply" (HSSS), endorsed in 2005 and was supported by Russian Federal Agency for Science and Innovations (State contracts #: 02.516.11.6150, 02.516.11.6016 and 02.516.11.6017) and Russian Foundation for Basic Research (Projects #: 06-08-01614-a, 07-08-12181-ofi)

References

[1] *Verbetsky V.A., Malyshenko S.P., Mitrokhin S.V., Solovey V.V.* Metal hydrides: Properties and practical applications // International Journal of Hydrogen Energy. 1998. V. 23. № 12. P. 1165.

[2] *Tarasov B.P., Lototskii M.V., Yartys V.A.* Problem of hydrogen storage and prospective uses of hydrides for hydrogen accumulation. Russian Journal of General Chemistry. 2007. T. 77. № 4. C. 694-711.

[3] Malyshenko S.P., Borzenko V.I., Dunikov D.O. et. al. Modeling of Thermophysical Processes in Me-H Cleaning Systems, Hydrogen Energy Progress XIII. Proc. of the 13th World Hydrogen Energy Conference, Beijing, China, June 12-15, 2000. V.2. P. 1323-1327

[4] *Artemov V.I., Lazarev D.O., Yan'kov G.G., Borzenko V.I., Dunikov D.O., Malyshenko S.P.* The effect of non-absorbable gas impurities on heat and mass transfer in metal-hydride devices for storage and purification of hydrogen. High Temperature. 2004. T. 42. № 6. C. 987-995.

[5] *Artemov V.I., Yankov G.G., Karpov V.E.* and Makarov M.V. Numerical Simulation of Processes of Heat-and-Mass transfer in Items of Heat and Power Equipment //Thermal Engineering. 2000. ‹ 7. V. 47. P. 632.

[6] *Borovskikh O.V., Lazarev D.O., Yan'Kov G.G., Artemov V.I.* Finning efficiency of a metal-hydride reactor's active volume. Thermal Engineering. 2009. T. 56. № 3. C. 235 - 238.