

Experimental Investigations of Heat and Mass Transfer Processes in Metal Hydride Porous Bed of Hydrogen Storage and Purification Unit

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Experimental Investigations of Heat and Mass Transfer Processes in Metal Hydride Porous Bed of Hydrogen Storage and Purification Unit

- Heat and mass transfer in metal hydride porous beds greatly affects hydrogen storage and purification devices efficiency
- Understanding of heat and mass transfer peculiarities in micro- and nano-structured materials at sorption/desorption processes with big volumetric and thermal effects is lacking
- Adequate mathematical models and their experimental verification are needed to optimize reversible solid-state material hydrogen storage systems

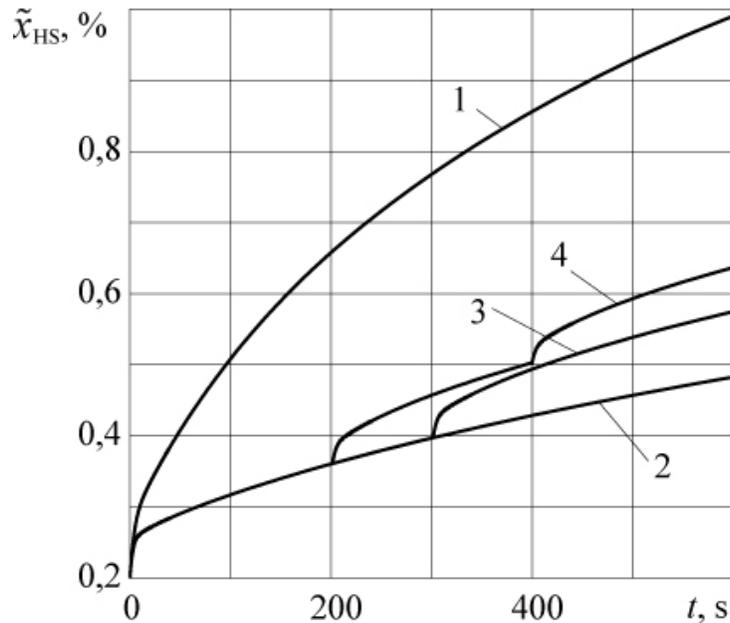
Basic Peculiarities of Heat and Mass Transfer Processes at Hydrogen Sorption/Desorption in MeH Porous Media

- **Big thermal effect** of hydriding/dehydriding reaction and the necessity to arrange efficient heat removal and application
- **Low effective thermal conductivity** of MeH beds
- **Volumetric effect** connected with considerable change of particle bed volume during the reaction
- **Influence of non-absorbable admixtures** on effective thermal conductivity and thereby on the storage and purification unit efficiency

LITP IVTAN Work Scope in the Field of Solid-state Reversible Hydrogen Storage Systems

- Experimental investigations of heat and mass transfer processes in metal hydride porous bed of hydrogen storage and purification units: temperature fields, sorption dynamics, calorimetric effects, influence of admixtures
- Development and experimental verification of new engineering solutions for MeH storage and purification units: heat exchanger design variation, operation mode optimization
- System integration in hydrogen storage for different applications such as FC power supply
- Numerical modeling of porous media (thermal and geometrical properties) and experimental definition of new material thermo physical properties: effective thermal conductivity measurement
- Modeling of heat and mass transfer processes in metal hydride porous bed of hydrogen storage and purification units (in collaboration with *Moscow Power Engineering Institute*)

Mathematical Modeling



Curve 1: absorption of pure hydrogen.
 Curve 2: gas mixture with the inlet proportion
 Curves 3 and 4: PSA-like absorption modes

Admixtures concentrate in the reactor during a short period of time in the beginning of the process:

- high rate of hydrogen absorption
- great heat effect of reaction

As a result hydrogen absorption rate is limited by hydrogen diffusion.

Expulsion considerably increases the efficiency of the metal hydride reactor charging

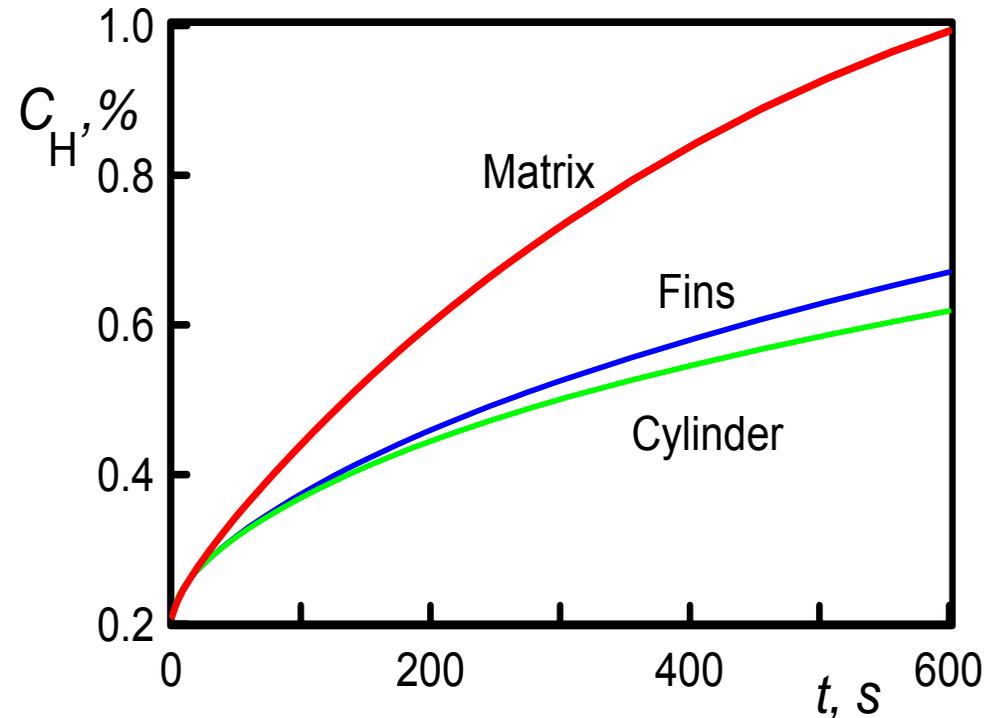
Mathematical Modeling

Figure shows temporal evolution of absorbed hydrogen mole concentration for three different reactor types.

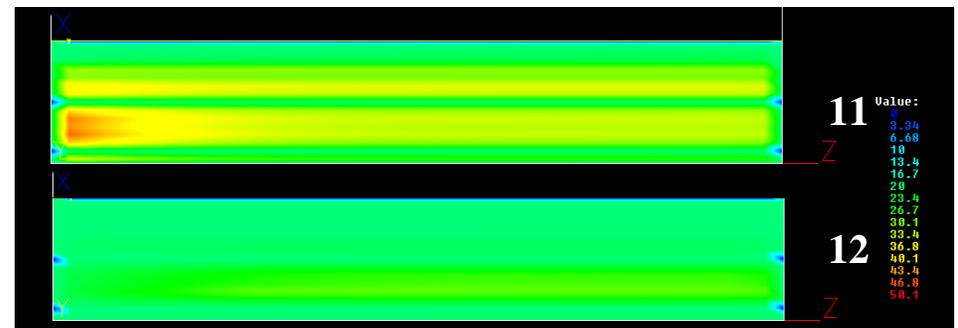
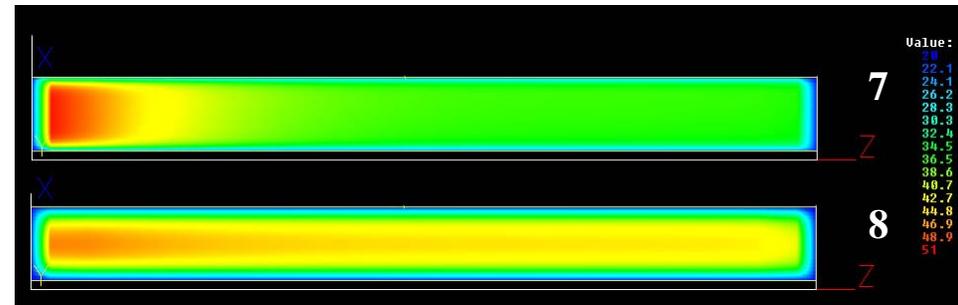
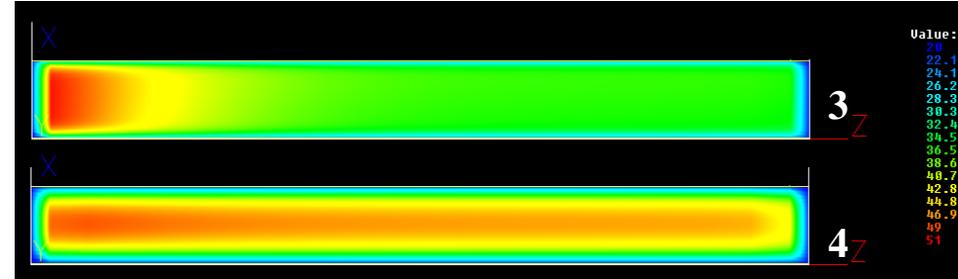
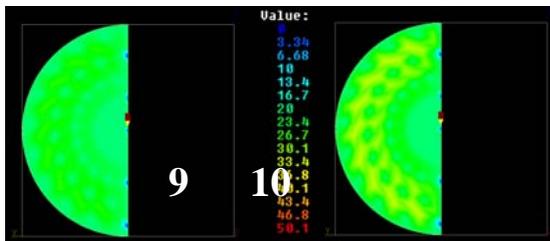
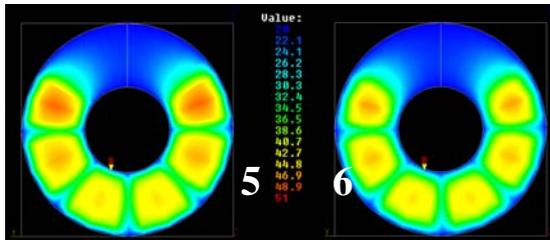
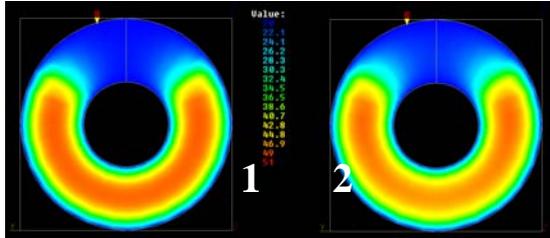
Use of the fins results in increase of absorbed hydrogen concentration on 8% at charging time of 10 min.

Use of tube matrix for porous bed cooling results in increase of absorbed hydrogen concentration on 40% at charging time of 10 min.

Thus the matrix embodiment of the hydrogen accumulator design seems to be most optimal in terms of thermal efficiency.



Mathematical Modeling



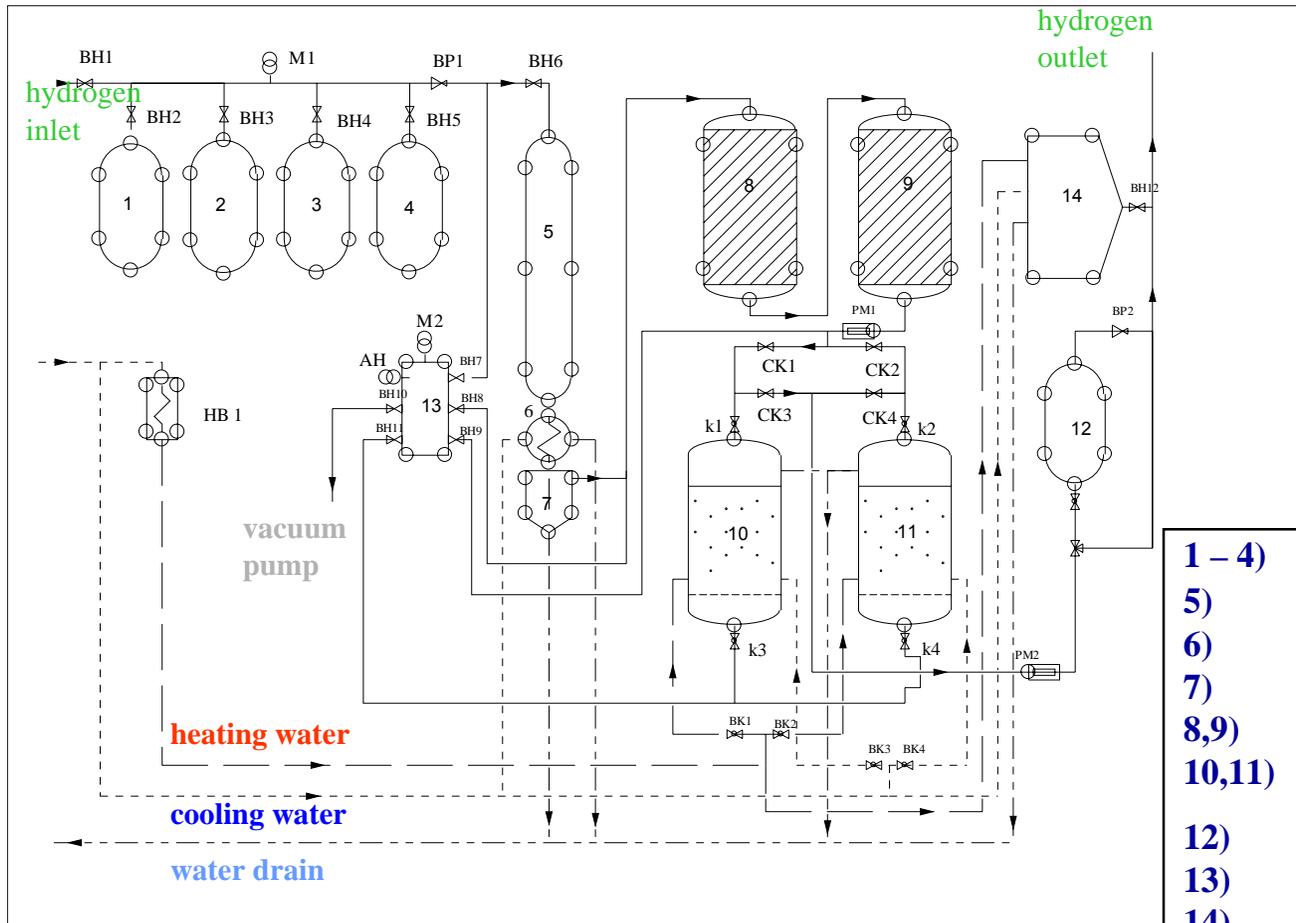
Field of gas temperature for three variants of MeH unit heat exchanger design:

1, 5, 9 - at the inlet cross-section after 600 s;

2,6,10 - at the central cross-section after 600 s;

3,7,11 - at longitudinal section ($\varphi = \pi$) after 50 s; 4,8,12 — at longitudinal section ($\varphi = \pi$) after 600 s.

LITP IVTAN Experimental Facility for Complex Investigations of Solid-state Reversible Hydrogen Storage and Purification Systems



- | | |
|--------|--------------------------------|
| 1 - 4) | Gas manifold |
| 5) | De-oxygenizer |
| 6) | Cooler |
| 7) | Water separator |
| 8,9) | Dryer |
| 10,11) | MeH storage/purification units |
| 12) | Probe cylinder |
| 13) | Humidity check unit |
| 14) | MeH storage unit |

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Parameters of the test system

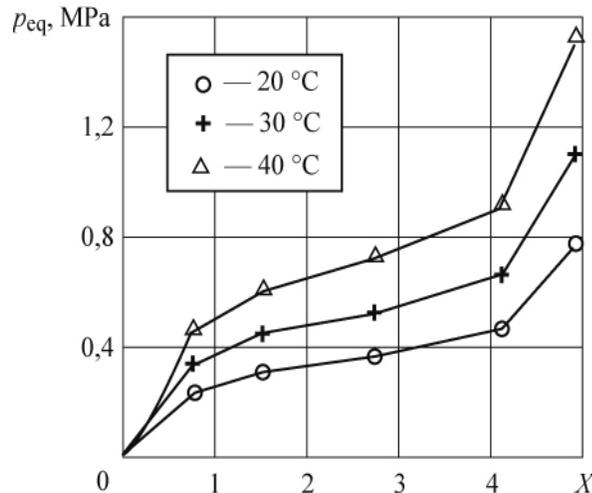
Mass of MeH ($Mm_{0,8}La_{0,2}Ni_{4,1}Fe_{0,8}Al_{0,1}$): **5 kg** per purification unit

Mass of MeH ($La_{0,98}Ce_{0,02}Ni_{4,65}Al_{0,15}$): **159 kg** in storage unit

Working pressure: **10 atm**

Cooling water: **t < 15 °C**

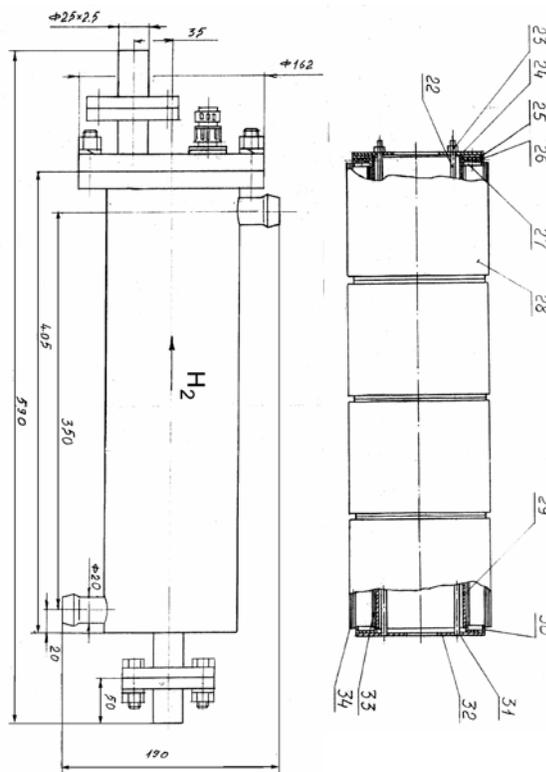
Heating water: **t > 85 °C**



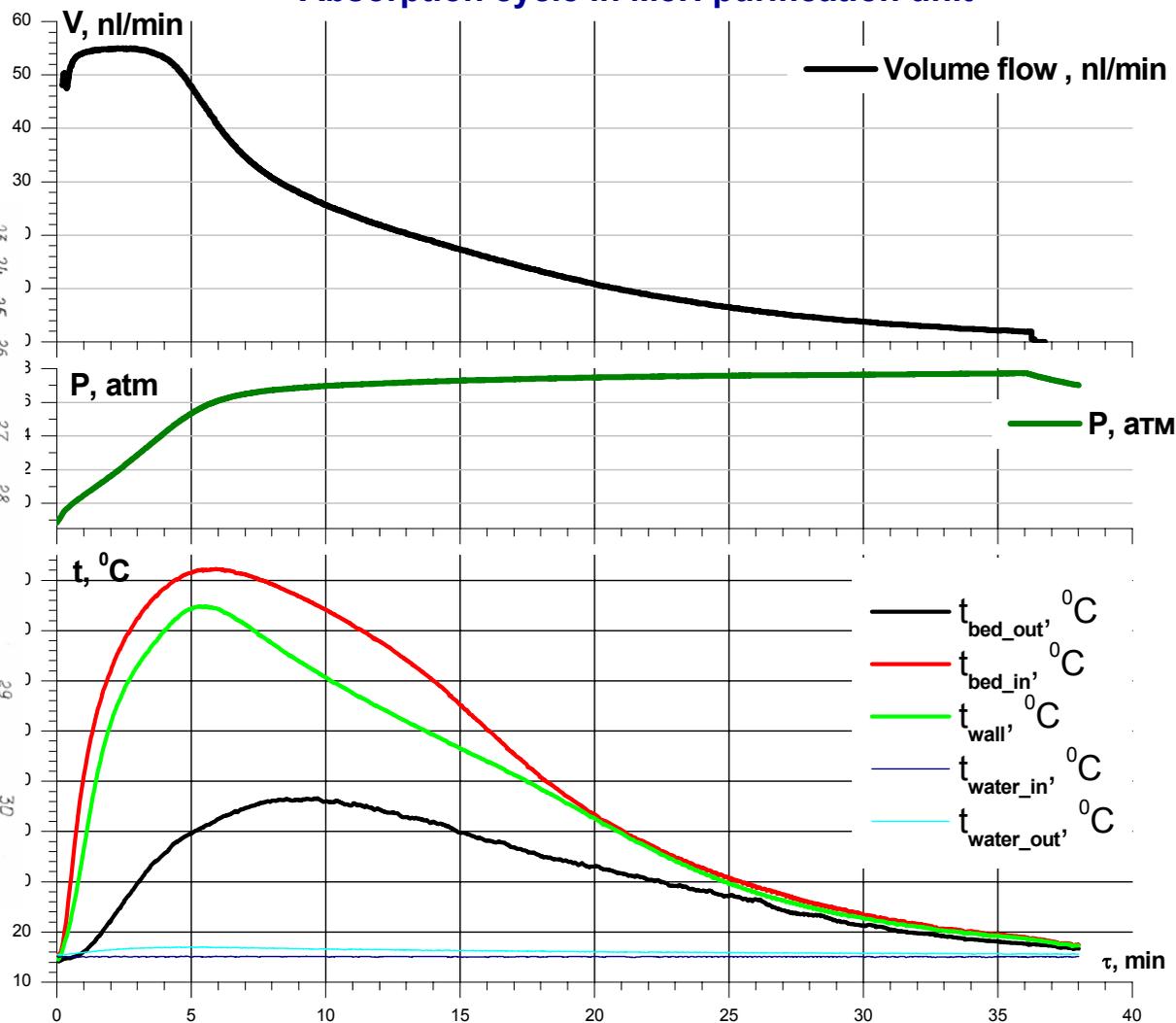
Experimental adsorption pressure - composition isotherms of $M_{0,8}La_{0,2}Ni_{4,1}Fe_{0,8}Al_{0,1}$

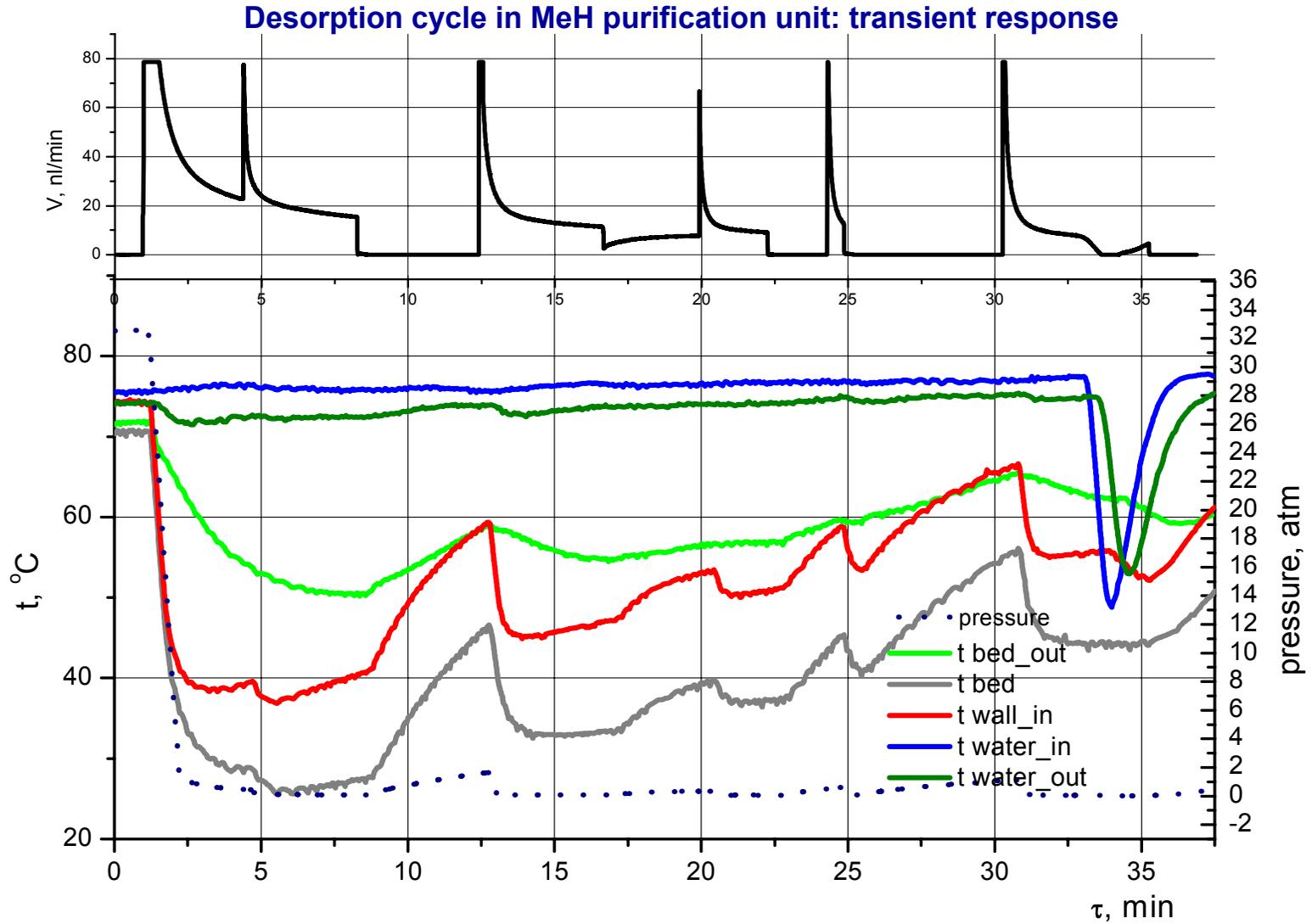


Cartridge type MeH Hydrogen storage and purification unit

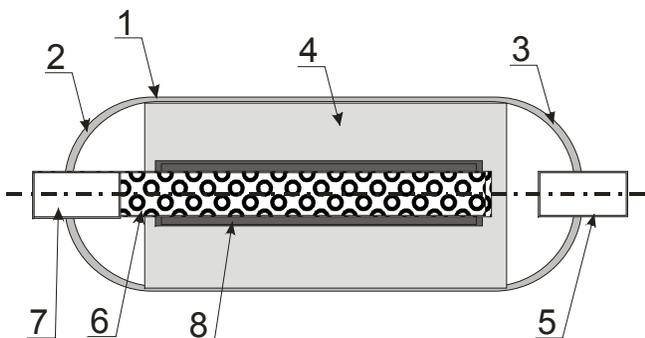


Absorption cycle in MeH purification unit



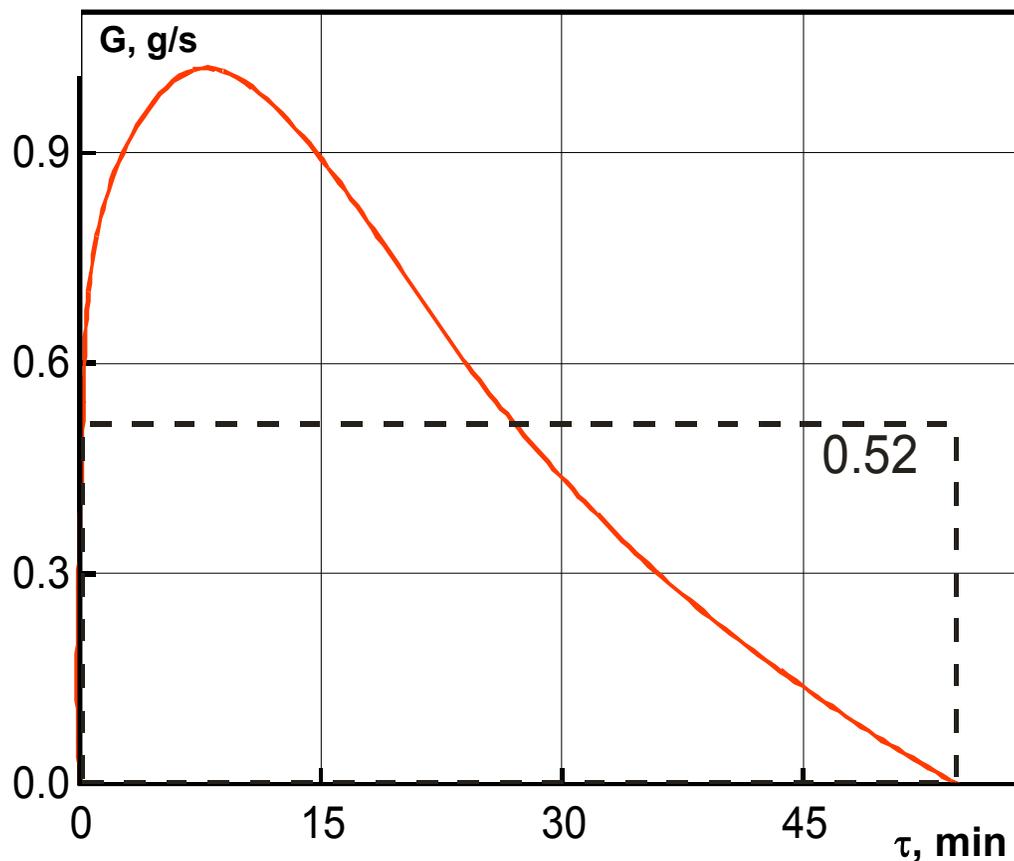


159 kg MeH storage unit

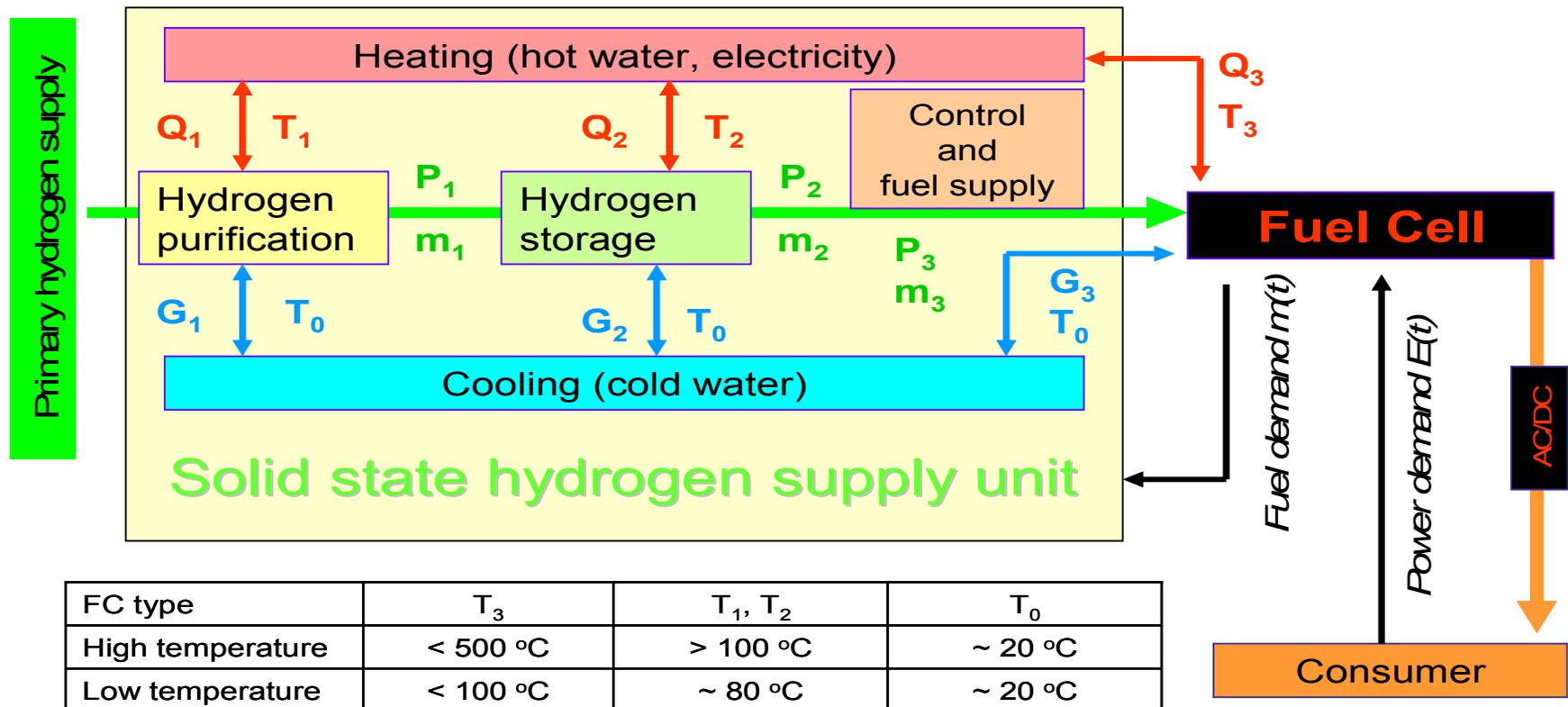


1 – steel ampoul; 2,3 – spherical bottoms;
4 – hydriding material; 5 – connection; 6 –
connection-filter; 7 –gas connection; 8 –
filter.

Storage unit tests, 0.52 g/s average capacity



The integration of solid state hydrogen storage into the FC power supply systems results in appearance of new possibilities to increase overall energy efficiency of the power supply system together with the appearance of new technical challenges.



Conclusions

The created experimental facility for complex investigations of solid-state reversible hydrogen storage and purification systems together with the developed 2-D and 3-D numerical model of heat and mass transfer at sorption form a tool for solving the tasks of

- efficiency improving of MeH hydrogen storage and purification devices;
- development of new reactor types optimized for fast recharge and hydrogen purification;
- development of reversible solid state hydrogen storage for PEM fuel cell power supply system with advanced thermal management, optimized power load modes and transient response.