TARGETED COMPREHENSIVE PROGRAM
SCIENTIFIC RESEARCH
NAS OF UKRAINE

Development of scientific foundations for obtaining, storage and use of hydrogen in autonomous power supply systems

Metal-hydride accumulator for hydrogen supply systems to fuel cells

project № 13-21

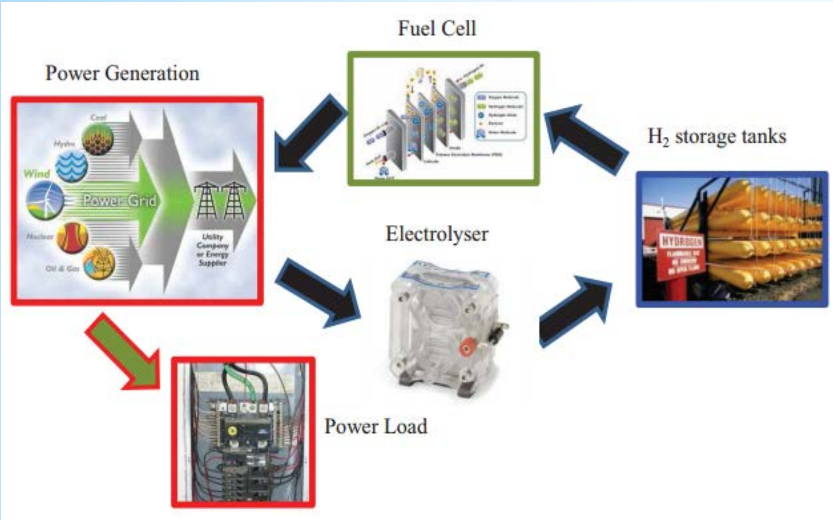
Scientific adviser: acad. NASU Matsevytyi Yu.M.
Performers: D.Sc. Avramenko A.N., Ph.D. Chorna N.A.
A.M. Pidhorny Institute of Mechanical Engineering Problems of NASU

The purpose of the research of the project was :

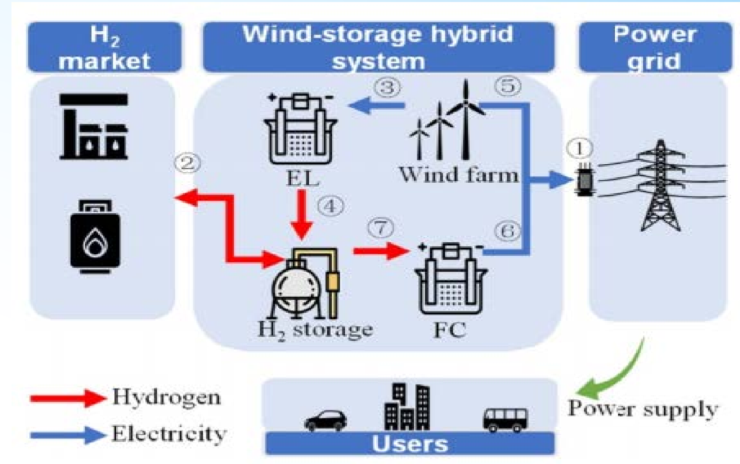
To develop of scientific and engineering solutions to improve the reliability of power supply of stand-alone systems and mitigate the environmental burden by using hydrogen technologies for energy storage.

To achieve project goals it was planned to determine the required amount of hydrogen for the operation of fuel cells; determine the optimal operating modes of the metal-hydride hydrogen storage system in accordance with its specified characteristics; to develop the design of a metal-hydride accumulator and to synchronize its dynamic characteristics with the operating mode of the fuel cell.

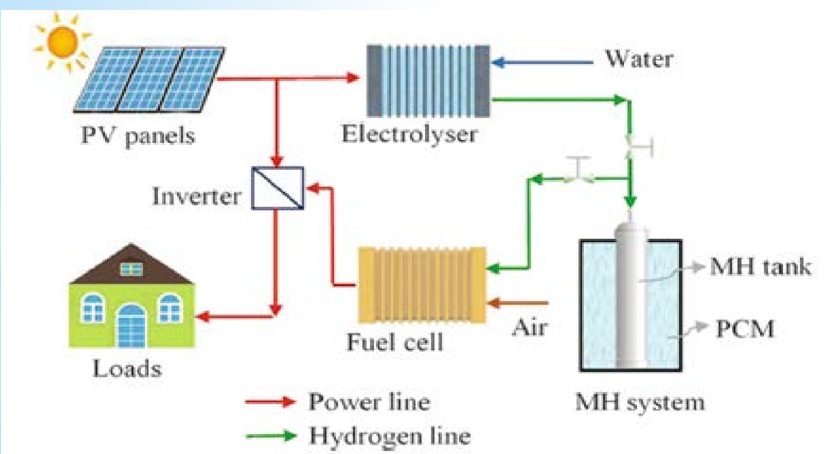
General concept of the organization of the energy system



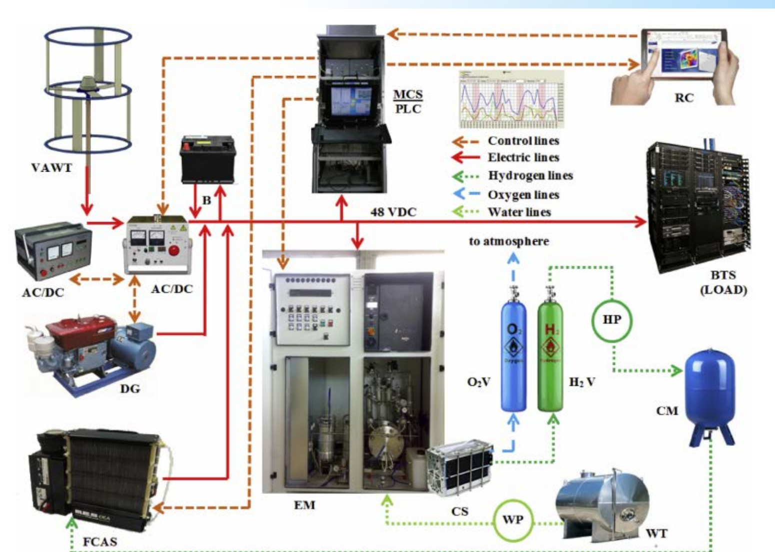
Research by French scientists Fédération FCLAB (France)



Research National Research Centre for Thermal Power Engineering and Technology, North China Electric Power University, China



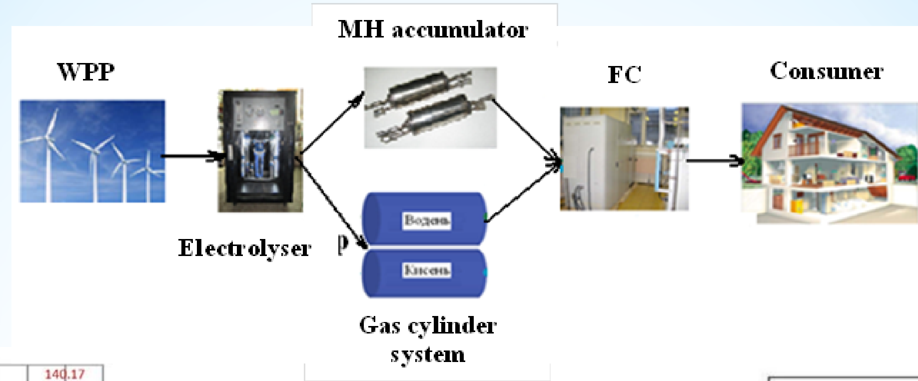
Autonomous solar-hydrogen system

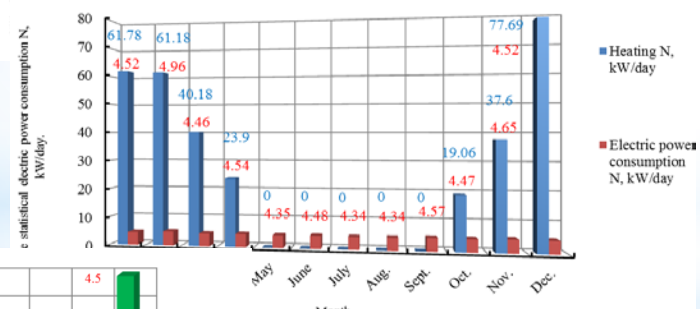


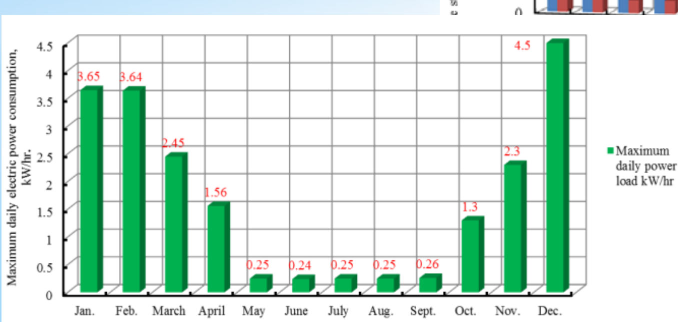
Wind power plant

Thermodynamic analysis of a system "Metal-Hydride Hydrogen Storage - Fuel Cell"

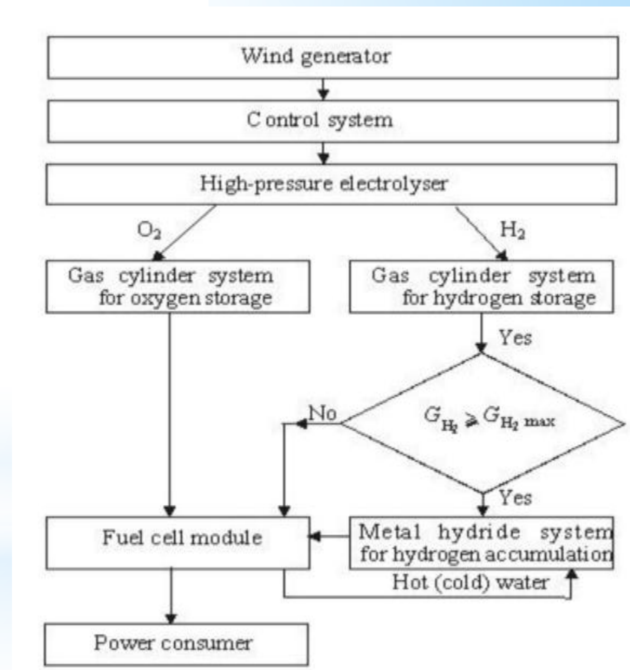
SCHEME OF AN AUTONOMOUS POWER PLANT







Estimated maximum electric power load in a stand-alone house



Generalised algorithm for design of a stand-alone energy supply system

Fuel cells for autonomous energy systems

APPLICATIONS

Application type	Portable	Stationary	Transport
Definition	Units that are built into, or charge up, products that are designed to be moved, including small auxiliary power units (APU)	Units that provide electricity (and sometimes heat) but are not designed to be moved	Units that provide propulsive power or range extension to a vehicle
Typical power range	1 W to 20 kW	0.5 kW to 2 MW	1 kW to 300 kW
Typical technology	PEMFC DMFC SOFC	PEMFC MCFC AFC SOFC PAFC	PEMFC (DMFC) (SOFC)
Example	• Small 'movable' APUs (campervans, boats, lighting) • Military applications (portable soldier-borne power, skid-mounted generators) • Portable products (torches, battery chargers), small personal electronics (mp3 player, cameras)	• Large stationary prime power and combined heat and power (CHP) • Small stationary micro-CHP • Uninterruptible power supplies (UPS) • Larger 'permanent' APUs (e.g. trucks and ships)	• Materials handling vehicles • Fuel cell electric vehicles (FCEV) • Trucks and buses • Rail vehicles • Autonomous vehicles (air, land or water)

FUEL CELL TYPE CLASSIFICATION

Types of fuel cells, their scope and software simulation for a fuel cell

FUEL CELL MODELING SIMULATION SOFTWARE

Application type	Name of Fuel Cell				
	PEMFC	AFC	PAFC	MCFC	SOFC
Stationary					
•HRES	Modelica, MATLAB				
•Gas turbine power plant				MATLAB	gPROMS, MATLAB, Cycle-Tempo, Hysys, Aspen, ProII, ThermoFlex, GATE/Cycle
•Heat and power (CHP)	Aspenplus				
Transport					
•Fuel cell electric vehicles (FCEV)	GT- SUITE, MATLAB/SIMULINK,Modelica				Modelon
•Autonomous vehicles (air)					Process Simulator, CAMEL-Pro™, MATLAB

Proton-exchange membrane fuel cell calculation

MODELING OF PEMFC

$$V_{cell} = E_{Nernst} - V_{act} - V_{ohm} - V_{conc}$$

$$E_{Nernst} = -\Delta G / nF$$

$$E_{Nernst} = 1{,}482 - 8{,}45x10^{-4}T + 4{,}308x10^{-5}T\ln\left(P_{H_2}P_{O_2}{}^{0{,}5}\right)$$

$$E_{Nernst} = 1{,}482 - 8{,}45x10^{-4}T + 4{,}308x10^{-5}T\ln\left(P_{H_2}P_{O_2}{}^{0{,}5}/P_{H_2O}\right)$$

$$V_{act} = 9.514x10^{-1} - 3.12x10^{-3}T + 1.87x10^{-4}T\ln(i) - 7.4x10^{-5}T\ln(C_{O_2})$$

$$C_{O_2} = P_{O_2}/5.08x10^{6}xe^{(-498/T)}$$

$$R_{cell} = R_i + R_c + R_e$$

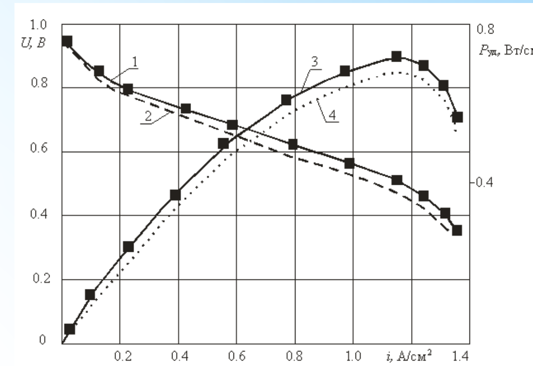
$$V_{ohm} = iR_{cell}$$

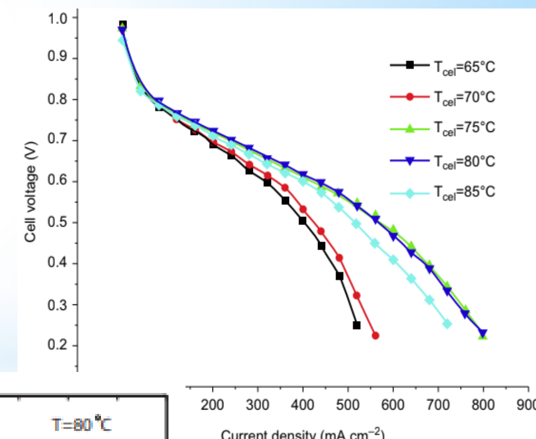
$$R_{cell} = 1.605 \times 10^{-2} - 3.5 \times 10^{-5}T + 8 \times 10^{-5}i$$

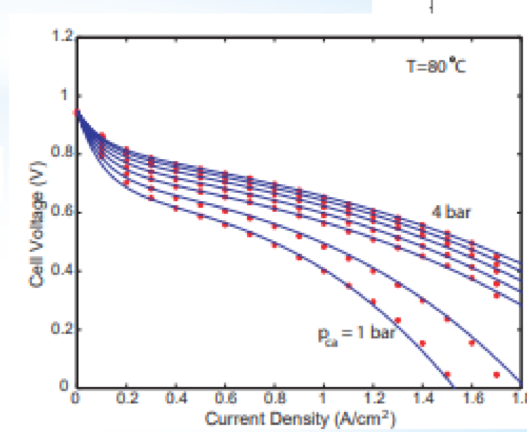
$$V_{ohm} = 1.605 \times 10^{-2}i - 3.5 \times 10^{-5}Ti + 8 \times 10^{-5}i^2$$

$$V_{conc} = -4.08 \times 10^{-5}T\ln(1 - i/i_{max})$$

RESULTS

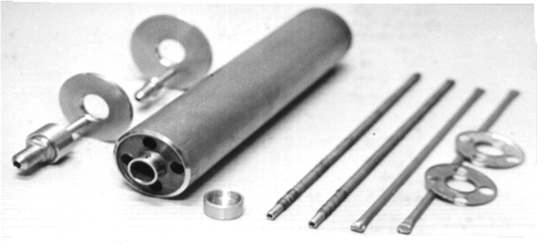




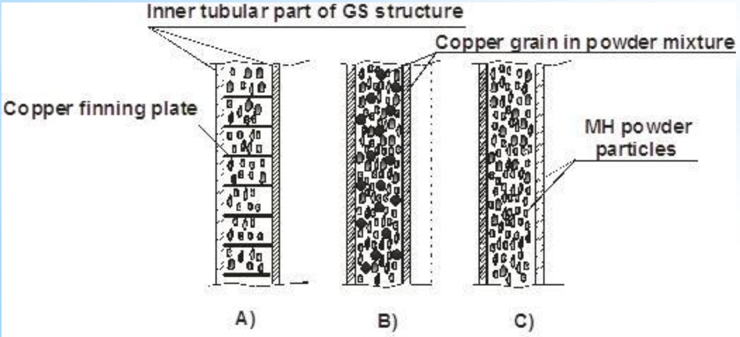


Synchronization of the operation of the Metal-Hydride Hydrogen Storage System and the PEMFC

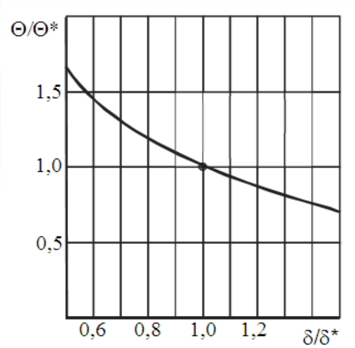
METAL-HYDRIDE HYDROGEN STORAGE SYSTEM

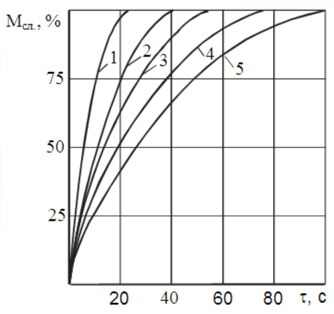


SIMULATION RESULTS

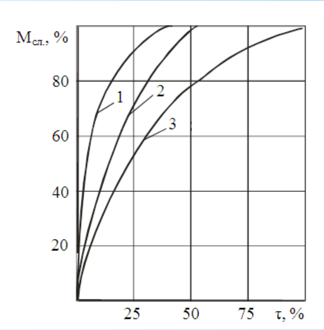


Sorption process intensification





1 – l = 0,001 м; 2 – l = 0,003 м;
3 – l = 0,005 м; 4 – l = 0,007 м;
5 – l = 0,01 м



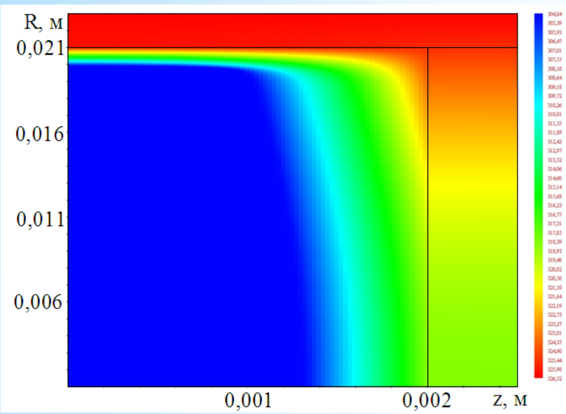
Formation of a rational design of metal hydride cells of a hydrogen accumulator

Synchronization of the operation of the Metal-Hydride Hydrogen Storage System and the PEMFC

SELECTION OF THE OPTIMAL PARAMETERS OF THE HEAT TRANSFER MATRIX FOR THE HYDROGEN ACCUMULATOR

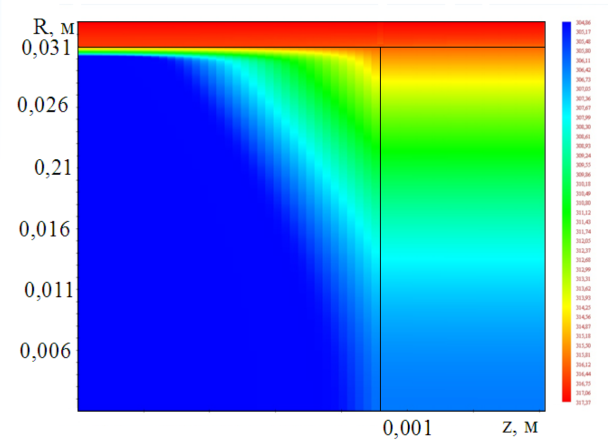
I option

R=Rвих. τ=70 c



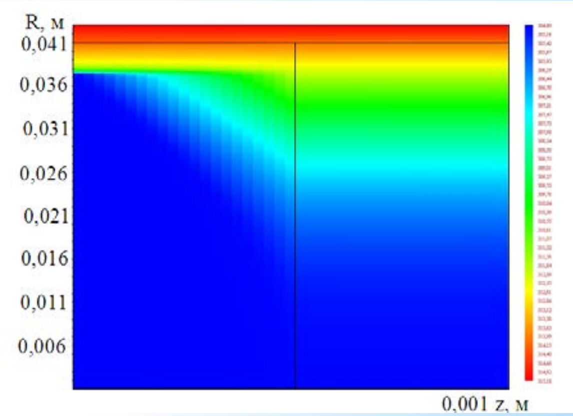
II option

R=1,5Rвих. τ=70 c

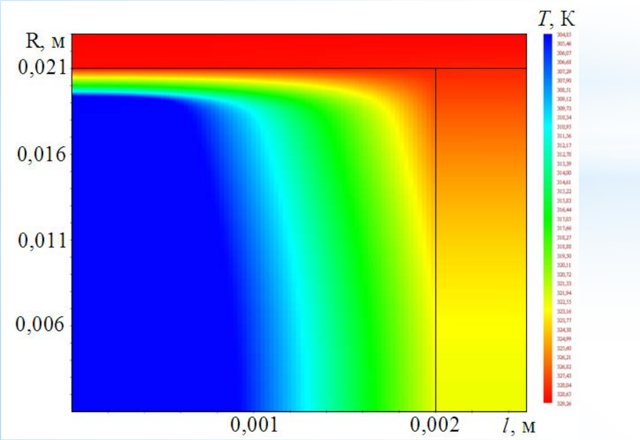


III option

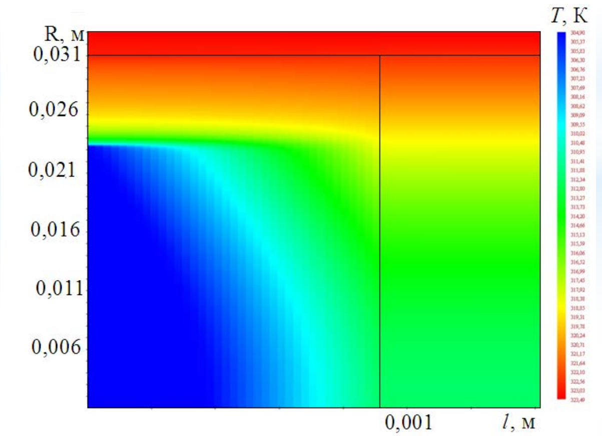
R=2Rвих. τ=70 c



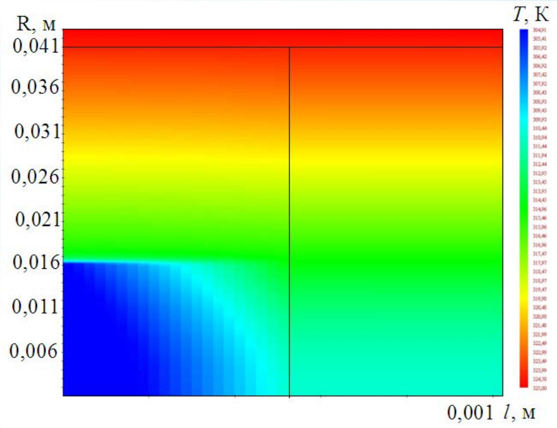
R=Rвих. τ=130 c



R=1,5Rвих. τ=130 c

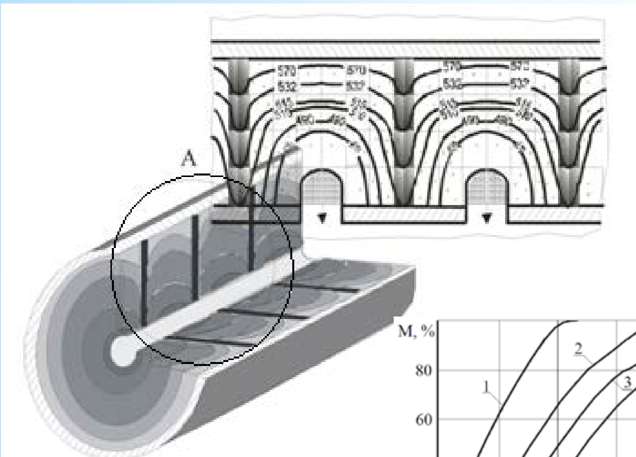


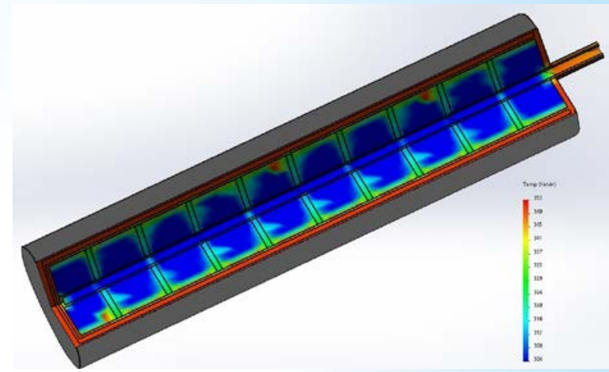
R=2Rвих. τ=130 c

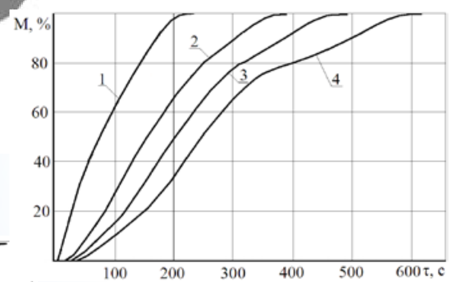


Synchronization of the operation of the Metal-Hydride Hydrogen Storage System and the PEMFC

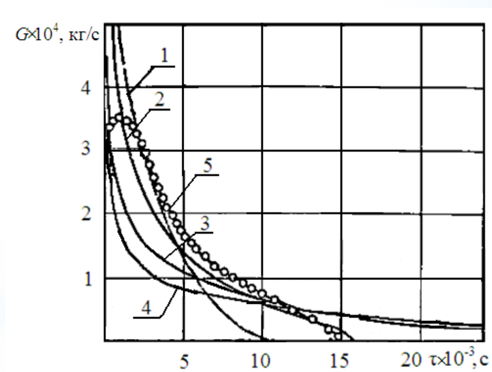
SIMULATION RESULTS



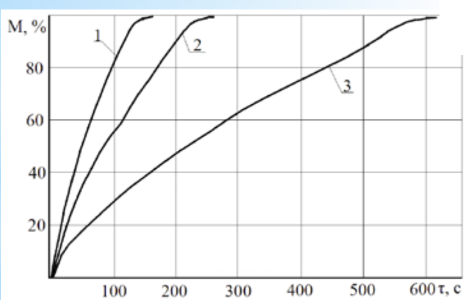




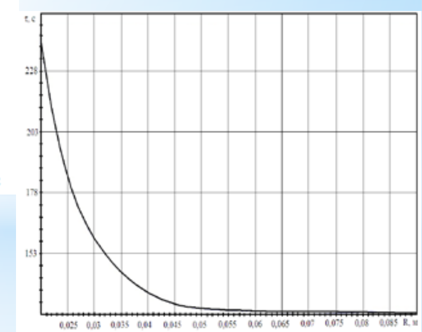
1 – α=3337 Вт/(м2·K); 2 – α=700 т/(м2·K); 3 – α=500 Вт/(м2·K); 4 – α=400 Вт/(м2·K)
Change in the mass flow rate of hydrogen from the heat transfer coefficient



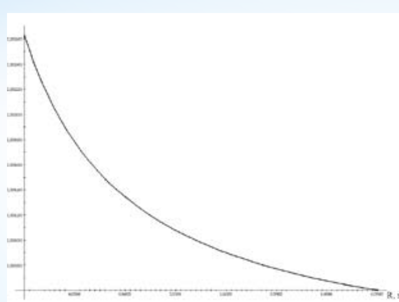
Time dependence of the mass flow rates of desorbed hydrogen by the MG accumulator



Change in the mass flow rate of desorbed hydrogen at α = 3337 W/(m² K) from the temperature of the coolant



Dependence of hydrogen desorption time from the radius of the hydrogen accumulator



Dependence of the heating surface on the radius of the hydrogen accumulator

CONCLUSION

1 An analysis of the operation of a fuel cell with a proton exchange membrane with a metal hydride hydrogen storage system is carried out. A regularity has been obtained between the amount of heat taken from the fuel cell during hydrogen desorption with its subsequent use to increase the power of the fuel cell and the throughput of the consumer's network.

2 As a result of the work, a calculation method was proposed that allows PEMFC to calculate the voltage and power, taking into account its electrical properties. Comparison of the calculation and experimental results for a fuel cell with a proton-exchange membrane is carried out. The deviations of the values of voltage and specific power for PEMFC, obtained as a result of calculation and experiment, did not exceed 5.7 %.

3 The offered mathematical model of thermal sorption interaction of an MH with hydrogen allows for calculating the transfer potentials (temperature, pressure and specific hydrogen mass content) of the sorption process in a GS for any time interval. Experimentally this is impossible. At the stage of designing the GS structure, the model allowed selecting its geometric and operating parameters to ensure effective hydrogen compression and quantitatively estimate exergy loss. The results of testing the developed experimental GS prototype with the technique offered have proved the declared cost-effectiveness characteristics of the metal hydride system.

4 On the basis of detailed calculations of the design of a hydrogen accumulator with a diameter of 0.046 m, in which the heat transfer matrix is made of copper plates, the influence of changes in the geometry of the internal ribbing of the accumulator on the process of heat and mass transfer in the MG is investigated. It was found that for the selected design of the hydrogen accumulator, the most preferred thickness of the ribbing of the plate is = 1.0×10^{-4} m in the range of thickness variation within 20 %.

5 When studying the effect of the distance between the plates on the hydrogen desorption process, it was found that with a decrease in the distance between the plates, the process intensifies. However, an increase in the number of rib plates per unit length of the accumulator leads to a reduction in the useful volume of the MG and, as a consequence, to a decrease in the hydrogen content in it (up to 13%). For the chosen design of the hydrogen accumulator, the distance between the ribbing plates with a thickness of = 1.0×10^{-4} m should not exceed 5.0×10^{-3} m.

6 Recommendations have been developed for synchronizing the operation of a metal hydride hydrogen storage system and a fuel cell as part of a power plant for autonomous power supply of a residential building.

Application area

Metal-hydride accumulator for hydrogen supply systems to fuel cells can be used as a part of wind-hydrogen or solar-hydrogen energy generating complexes on farms, livestock complexes, telecommunication companies, health resorts and other facilities that require reliable energy supply. The development is aimed at the use of autonomous power plants that use wind or solar energy to smooth the uneven energy supply and consumption in the utility sector.

Expected results

This methodology gives the possibility for more exact calculating the hydrogen storage metal-hydride systems operation as well as:

- for making the optimal choice of hydride materials to be used in these systems;
- for determining the structural parameters of the main basic elements and the mode parameters of their operation.

Approach to the creation of a metal hydride system for accumulating hydrogen and its supply to fuel cells has been substantiated.

Advantages

An alternative scheme of electricity and heat supply of an autonomous house without the use of imported fuel is proposed. The advantage of such a scheme is its closed nature, since hydrogen is produced on site to power the fuel cell, while the metal hydride hydrogen storage system is capable of carrying out absorption and its release processes due to the hot water resources available in the system.

PUBLICATION

1. A.M. Avramenko, N.A. Chorna, A.A. Shevchenko, A.L. Kotenko. Application of highly efficient hydrogen generation and storage systems for autonomous energy supply. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 2021, № 3, Pp. 69–74. https://doi.org/10.33271/nvngu/2021-3/069 (Scopus)

2. N.A. Chorna. Prospects for application of hydrogen technologies for autonomous power complexes based on renewable energy sources. *Scientific and Applied Journal Vidnovluvana energetika*, 2021, № 3(66), Pp. 18-32. https://doi.org/10.36296/1819-8058.2021.3(66).18-32.

3. N.A. Chorna. Research of the efficiency of fuel cell as part of autonomous power plants. *Journal of Mechanical Engineering*. – 2021. – Vol. 22, №. 4. – pp. 48–52. https://doi.org/10.15407/pmach2019.04.048.

4. Yu. Matsevytyi, N. Chorna, A. Shevchenko. Development of a perspective metal hydride energy accumulation system based on fuel cells for wind energetics. *Journal of Mechanical Engineering*. 2019. Vol. 22, № 4. Pp. 48–52.

5. A. Avramenko, N. Chorna. Adaptation of metal-hydride hydrogen storage technologies for autonomous power supply systems based on fuel cells // *XVI International Conference «HYDROGEN MATERIALS SCIENCE AND CHEMISTRY OF CARBON NANOMATERIALS»* (ICHMS '2019), Kiev, September 23–30, 2019. – 2019. – Pp. 88–89.

6. Chorna N., Shliakhov M. Use of Mathematical Modelling for Development and Creations of an Effective Design of a Metal-Hydride Hydrogen Accumulator. *MATERIALS OF 9 TH INTERNATIONAL FORUM «LITTERIS ET ARTIBUS»*, NOVEMBER 21-23TH, 2019, LVIV, UKRAINE. – Pp. 183-186.

7. N.A. Chorna , V.V. Ganchin Use of mathematical modeling to improve the mass and dimensions of metal-hydride plants. *Mathematical methods and physical and mechanical fields*. 2019. Vol. 2. № 3. Pp. 159–167.

Інститут проблем машинобудування ім. А.М. Підгорного НАН України

Дякуемо за увагу

A. PODGORNY INSTITUTE OF MECHANICAL ENGINEERING PROBLEMS, NASU,
2/10 Pozharsky St., 61046, Kharkiv, Ukraine

Thank you for attention