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GENERAL CONCEPT OF THE AUTONOMOUS HYDROGEN FUELLING STATION BASED ON PHOTOVOLTAIC AND METAL-HYDRIDE TECHNOLOGIES FOR FUEL CELL ELECTRIC VEHICLES

DOI 10.15589/SMI. 20170218

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Abstract. The promotion of hydrogen energetics into the transport sector is currently a priority in the development of the world economy. One of the efficient direction for modern vehicles is the usage fuel cells and hydrogen for its powering. The obstacle along this way is the high cost of hydrogen and the difficulty of storing it on Vehicles' board. The article considers the possibility of the solar energy usage for efficient hydrogen production and metal-hydride technologies for its purification, compression and storage into the filling station and on a board.

Keywords: Vehicle; Photovoltaic battery; Hydrogen; Metal-Hydride alloy and slurry; Fuel cell; Purification and Compression

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INTRODUCTION

At present time internal combustion engines (ICE) are the most spread as main and auxiliary ICE for vehicles, vessels, power generation, etc. Their application is associated with low energy efficiency, negative impact on the environment due to high emissions of harmful substances and the use of oil fuels. The vehicles with electric motors are alternative upon to existing ones.

There are two modern concepts of the electric vehicles: battery electric vehicles and electric vehicles with fuel cells. The main advantage of the battery electric vehicles is the developed infrastructure of power grids and charging stations, but the charging time is too prolonged (from 20 minutes in the fast charging mode and up to 8…10 hours. Unfortunately the fast mode significantly reduces life cycle of the electric batteries.

One of the advanced alternatives is concept of the fuel cell and hydrogen powered vehicles. It exist some problems which limit its wide implementation. There are the following: high cost of hydrogen production, insufficient amount of electricity production and transmission capacity of electric networks for mass charging of electric vehicles.

These problems can be solved by creation of the complexes for local hydrogen production by water electrolysis on the base of photovoltaic panels, hydrogen purification and compression on the base of metal-hydride technologies and hydrogen storage in ultra-light-weight high pressure thanks on the base of reinforced with carbon nanotubes or composite materials.

Implementation of this concept will allow to get rid of disadvantages which are inherent in vehicles with electrical batteries. The most of these are the following: high mass and cost, limited run distance and long charging time, short life cycle and recycling batteries pollution.

The charging duration of hydrogen high pressure tanks is 5...15 min and is comparable with the ICE diesel/gasoline fueling terms and conditions. One of the main obstacles to expanding vehicles on fuel cells is the deficit of hydrogen and its filling stations. At present it is known a number of solutions for the creation of hydrogen fueling. However, today there is no single standard solution for hydrogen charging.

Until today, vehicles running on hydrogen (both fuel cells and equipped with ICE that consume hydrogen), several options for its storage are used. There are high pressure tanks with hydrogen gas compressed at 35…70 MPa. Judging by the vehicles technologies and concepts the combination of fuel cells with tanks at 70 MPa will be the most common variant of hydrogen technology promotion in the coming years.

In connection with the variety of hydrogen storage options on board vehicles, it is actual to develop autonomous fueling stations with photovoltaic panels for electricity production with following hydrogen production by electrolysis, hydrogen purification and compression by metal-hydride technology and hydrogen storage in super high pressure tanks or metal-hydride tanks with the possibility of hydrogen charging at different pressures from 35 MPa up to 150 MPa.

THE MAIN PRINCIPAL

The main diagram of an autonomous super high pressure hydrogen production and fueling station is shown on Fig.1. It operation process is the following. Photovoltaic panels generate electricity from the solar insulation. This electricity enters into the electric power controller which optimized its parameters for electrolyzer. The same time wind power unit supply electricity to the electric power controller as well.

When solar insulation and wind power are not enough for hydrogen generation, electricity supply enters from the utility grid. Hydrogen from electrolyzer enters into hydrogen purifier and follows into metal-hydride compressor. This device executes the functions of hydrogen compression up to super high pressure 150 MPa and provides final hydrogen purification up to 0.999.

Generated high pressure hydrogen may be stored in high pressure kevlar composite tanks as gas of in metal-hydride slurry in special tanks as liquid.

High purity and super high pressure hydrogen enters into storage tank and further for fueling vehicles. Electrolysis making up is supplying from appropriate tanks. Generated hydrogen enters to consumers after processing into purifier and compressor.

One of the important devices of the fueling station is photovoltaic panels. Efficiency of these panels from well-known producers is shown on Fig.2. This data analysis allows to recommend photovoltaic panels of middle efficiency. High efficient panels are too expensive and can be recommended for special usage only. General power of photovoltaic panels depends on hydrogen consumption for fueling vehicles equipped with fuel cells. These fueling station can serves and vehicles with ICE hydrogen powered.

One of the important devices of the fueling station is metal-hydride compressor. Its operation bases on unique properties of special reversible hydride-forming intermetallic alloys like as $LaNi_5$, $LaNi_{4.5}Al_{0.5}$, FeTi, $TiCr_2$, $TiCr_{1.1}V_{0.9}$, $TiCr_{1.1}V_{0.45}Nb_{0.45}$ and others [1].

Reversible reaction:

$$M_{solid} + H_{2\,gas} \leftrightarrow MH_{x\,solid} + Q_{heat}.$$

For instant:

$$LaNi_5 + 3H_2 \leftrightarrow LaNi_5H_6 + 14.4\ \text{MJ/kg}\,H_2;$$
$$Mg_2Ni + 2H_2 \leftrightarrow Mg_2NiH_4 + 31{,}9\ \text{MJ/kg}\,H_2;$$
$$TiFe + H_2 \leftrightarrow TiFeH_2 + 31{,}9\ \text{MJ/kg}\,H_2.$$

Energy efficiency of these alloys depends on temperature range of hydrogen absorption/desorption, amount of absorbed hydrogen, thermodynamic properties, hysteresis etc. For instance, one of the most effective material is $MmNi_{4,5}Al_{0,5}$ with desorption pressure of 3.87 MPa at 500 K, and mass hydrogen sorption capacity ratio of 0.91 %. Its main properties, researched and developed by the authors, are shown in Fig. 3.

Hydrogen absorption by these materials is accompanied with the release of the adsorption heat. Hydrogen desorption require heat input and pressure of hydrogen output depends on heat temperature. The adsorption/desorption heat amount is in the range of 8…15 MJ/kg H2 for various hydride-forming materials [5]. Thermal effect of the hydrogen absorption/desorption process is uses in heat pumps, chillers, compressors, hydrogen. [6, 7, 8, 9]. But, unfortunately, these equipment have discreet operation principal at present.

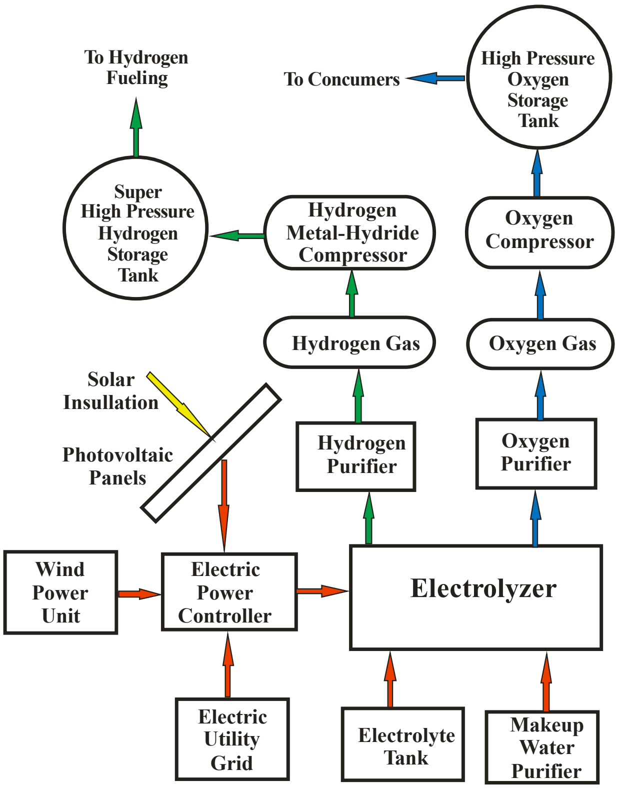

Fig. 1. An autonomous fueling stations with photovoltaic panels for electricity production with following hydrogen production by electrolysis.

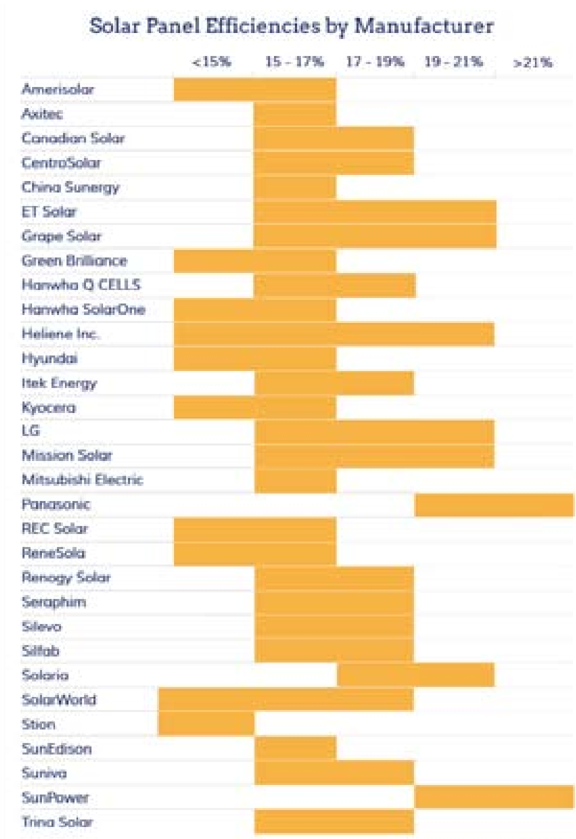

Fig. 2. Solar photovoltaic panels efficiency

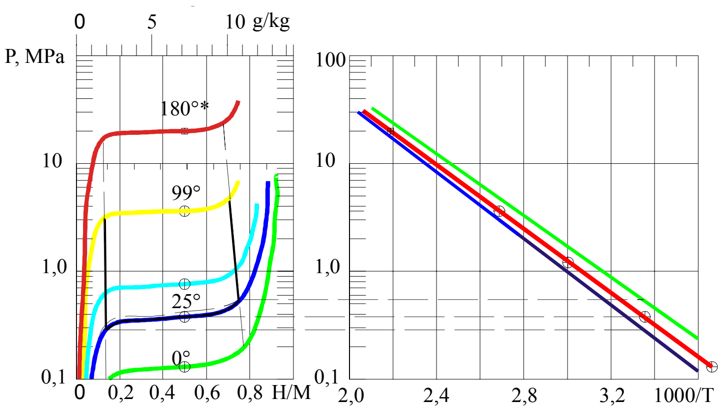

Fig. 3. The main properties of the metal-hydride alloy $MmNi_{4,5}Al_{0,5}$ [4]

The principal disadvantages of discreet operation facilities are the following: huge heat losses in heat and mass exchangers, absorbers and desorbers, as the consequences of unstable pressures, temperatures and hydrogen flow transfer, huge masses and dimensions of the devices. Thermodynamic efficiency of the discreet operation devices is unsatisfactory — less than 10%. These disadvantages can be corrected by the usage of continuous operation metal-hydride equipment. Continuity operation is achieved by metal-hydride slurry circulation between heat and mass transfer devices of the recovery heat facility [10].

THE DIAGRAM AND DESIGN SOLUTION

The principal diagram of metal-hydride unit for hydrogen purification, compression and storage of continuous operation is shown on Fig. 4.

The operation principal is the following. At the first stage hydrogen from electrolyzer enters into condenser where water steam is extracting from gaseous mixture. Next hydrogen enters into the second stage of fully purification in absorber and stripping devices. Hydrogen has reaction with hydride-forming alloy and is converting into slurry. Main base of slurry is pounder of hydride and inert silicon liquid.

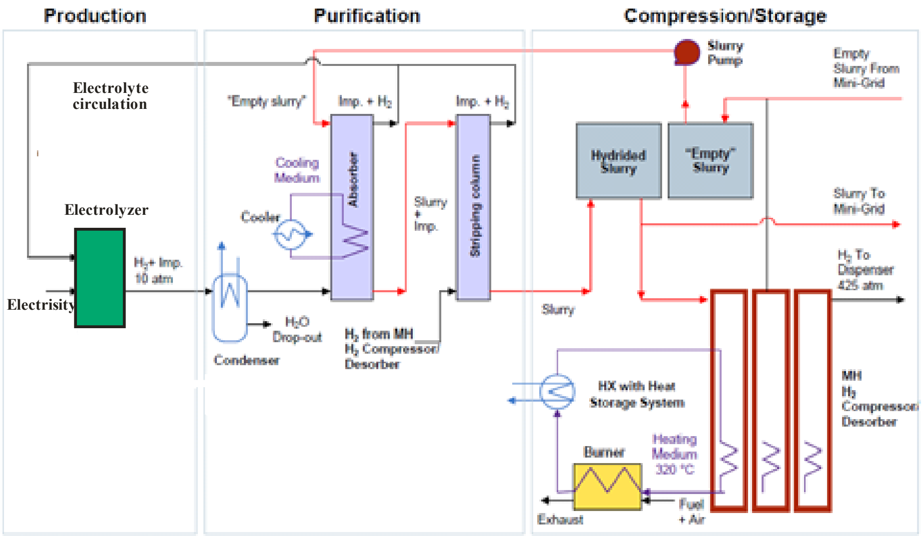

Fig. 4. The metal-hydride unit for hydrogen purification, compression and storage

Hydrogen Gasoline

Simultaneous ignition
Hydrogen and gasoline

Hydrogen Gasoline

One minute after ignition hydrogen fire nearly extinguished

One minute and 30 seconds after ignition. Gasoline image enlarged to show detail; all hydrogen fuel burned so picture of hydrogen car is minimized

Fig. 5. Illustration of gaseous hydrogen ignition and burning compere with gasoline

Fig. 6. Results of kevlar composite tank explosion

From this unit slurry enters into compression unit continuous operation. There slurry with thermosorption in sorption/desorption process relist hydrogen. Hydrogen is extracting from slurry with super high pressure up to 150 MPa. Then hydrogen enters into the storage tanks and fueling equipment.

THE SAFETY

An autonomous solar-hydrogen filling station on the base of metal-hydride slurry devices is the safest technology for operation with hydrogen. Hydrogen is existing as inert metal-hydride slurry and is not flammable and not explosive.

Ignition and burning of the gaseous hydrogen is not more danger compare with gasoline. Fig.5 illustrates ignition and burning process in hydrogen and gasoline fueled vehicles.

Hydrogen storage in super high pressure kevlar composite tanks is more safe than standard metal tanks. Fig. 6 illustrates the results of kevlar composite tank explosion.

CONCLUSIONS

Autonomous hydrogen filling station based on photovoltaic and metal-hydride technologies for vehicles with fuel cells is one of the most effective economically and safe compare with other technologies of production, purification, compression, stoppage and fueling vehicles with fuel cells.

Статью рекомендует в печать
д-р техн. наук, проф. *Н. И. Радченко*

Acknowledgment: We would like to express sincere appreciation to all members of our research team who had participated in this project and had contributed their knowledge, skills and dedication.