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# HEAT PIPES IN NEW POWER SOURCES TECHNOLOGY

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## 1. Introduction

Portable electronic devices such as mobile phones, PDAs, laptop computers etc. form a great part of suggested contemporary market. Several companies such as Samsung, Toshiba and Panasonic are developing portable direct methanol fuel cells, as one of the best approaches to small fuel cell systems and a considerable amount of research is being conducted in this area. Fuel cells have important advantages over conventional batteries, such as increased operating times and reduced weight.

The goal of this work is to design and develop a new fuel cell cooling system based on heat pipe concept [1-5]. On the basis of the Luikov Institute activity in this area original heat pipe approach is done. The suggested cooling system based on heat pipe phenomena could be considered as an innovative manner for solving of the problem mentioned.

Heat pipes for fuel cell thermal management ought to have high effective thermal conductivity and be insensitive to the gravity forces. The vacant porous media for micro/miniature heat pipes is a metal sintered powder wick or a silicon/carbon porous wafer with biporous (micro/macro pores) composition, saturated with working fluid. Heat pipes fuel cell management can be performed in different ways:

1) Micro/mini heat pipes for fuel cells thermal management (< 10 W)
2) Heat pipes for fuel cells with moderate heat dissipation (10–100 W)
3) Heat pipes for portable fuel cells (> 100 W)
4) Heat pipes systems for stationary fuel cells (stationary electricity generation)

## 2. Different designs of heat pipes for fuel cell thermal management

### *2.1 Micro/mini heat pipes for fuel cells thermal management*

Micro/miniature heat pipes have cylindrical, flattened or flat shape and can be embedded into bipolar plate of fuel cell (FC). Micro/mini heat pipes (fig.1) for proton exchange membrane fuel cells (PEMFCs) operate at relatively low temperatures around 80–100 °C. Micro (MHP) and miniature heat pipes (mHP) are small scale devices used for micro/mini fuel cells cooling. Hydraulic diameter of microchannels for fluid flow is about 10–500 μm in MHP and 2–4 mm in mHPs. Smaller channels application is desirable because of two reasons: (i) higher heat transfer coefficient, and (ii) higher heat transfer surface area per unit flow volume.

The most efficient thermal management of micro/mini fuel cells can be performed when two-phase thermal control typical for an animal body or plant leaves is realised. Thermal control realized by so called open-type micro heat pipes is feasible, if the heat loaded structures are covered with a thin porous layer, saturated with liquid [6–8].Gas diffusion layer and gas channels of PEMFC ought to be formed by the porous structure including macro and micro pores. There is a strong interaction between basic phenomena in heat pipes. Basic equations are related to vapour flow in the MHP channel, liquid flow in the capillary structure, interface position between the vapour and liquid (mechanical equilibrium yields interface curvature), radial heat transfer, vapour flow limit, capillary limit. Feedbacks may cause instabilities, waves, flooding, and performance jump. Optimisation of the new copper sintered powder wick in miniature heat pipes with outer diameter 3–4 mm and length up to 200 mm was carried out in the Luikov Institute, Minsk since 1997. The maximum heat transfer rate for these HPs is almost 50 W [5]. Original software was developed and used for prediction of cylindrical and flattened heat pipes (including mHP) characteristics [6]. Heat pipe family qualified geometry is: circular tube diameter 3–25 mm, flat heat pipe thickness 2–20 mm, length 0.1–0.8 m, wall thickness 0.2–1.0 mm. Pipe material is copper of 99.95% purity, wick is formed by copper sintered powder, layer thickness is being equal to 0.2–0.8 mm. Transport capacity is about 10–500 W. Water, methanol and propane are used as working fluids.

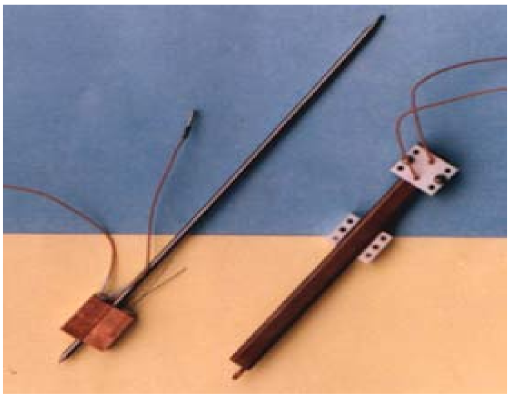

Fig. 1. Cylindrical and flattened miniature heat pipes for fuel cells thermal management developed in Luikov Heat and Mass Transfer Institute

*2.2 Loop heat pipes for fuel cells with moderate heat dissipation*

Loop heat pipes (LHP) are an attractive alternative for heat regulation, fig. 2. The performance of the evaporator depends on the transport properties of the wick, i.e. permeability, thermal conductivity as well as structural characteristics of the wick, namely homogeneous or heterogeneous porous system, narrow or wide size distribution of the pores. A new type of miniature loop heat pipe was investigated by the NASA Glenn Research Center, USA [9]. The principle application is electronic cooling at the chip level, but it is also very promising for the PEMFC stack cooling and thermal control. The heat pipe evaporator is constructed of silicon, such that there will be little thermal interface resistance between the source of the heat generation, the computer chip junction, and the working fluid. The device utilizes a coherent porous silicon wick that provides small effective pore radii [9], fig.3.

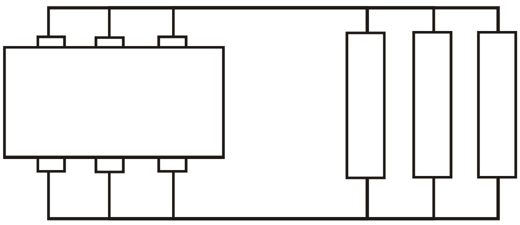

Fig. 2. Loop heat pipe with some evaporators embedded in the FC stack and condensers

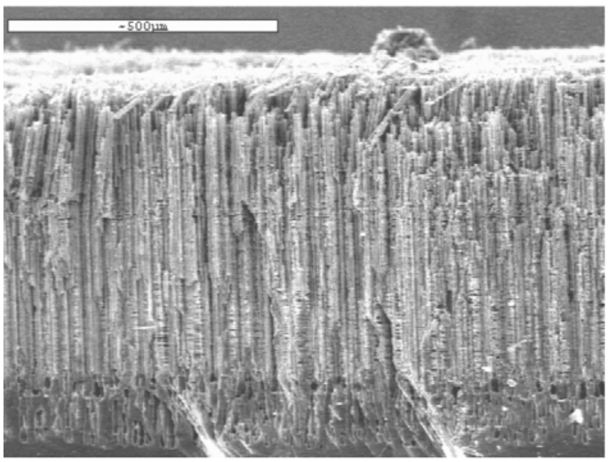

Fig. 3. Silicon porous structure for the LHP evaporator

This new technology is a type of microelectromechanical systems (MEMS) process that allows one to “drill” a pattern of micron-sized holes in a silicon wafer. In fuel cells and heat pipes, the flow characteristics in the porous media (gas diffusion layers or capillary wick) are useful in performance modeling. Permeability is a parameter that describes the relationship between pressure drop and mass transport through porous media. In heat pipes effective pore radius is a parameter used to describe the available pressure rise for liquid pumping [5, 9]. In the LHP there is a possibility to use an evaporator above the condenser, the vapour flows through the vapour channels towards the condenser and the liquid goes back the evaporator due to the capillary pressure head of the porous wick.

*2.3 Loop thermosyphons for portable fuel cells*

Since the loop thermosyphon has larger critical heat flux than conventional thermosyphon it is convenient to use it in many different applications, for example, for fuel cells thermal control. The loop thermosyphon evaporator requires a good thermal contact with a stack, the condenser ought to be cooled by air or water. The loop thermosyphon transports thermal energy from a heat source to a sink by natural convective circulation without any external power supply such as a pump. The thermosyphon evaporator and the condenser are installed separately, but they are connected to each other by small diameter bendable pipes. Due to the relation between momentum and energy transport theoretical analysis of the loop performance is very complicate, therefore it is necessary to solve these problems by experimental investigation before applying the loop thermosyphon to heat exchanger design.

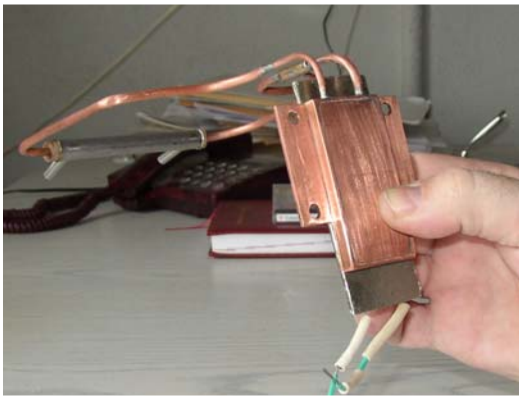

Fig. 4. Copper/water loop thermosyphon for the FC stack thermal management

Fig. 5. LHP flat evaporator made from copper with sintered powder porous structure and mini grooves for liquid suction

In the loop thermosyphon the heat transfer is considered to be affected by many factors, such as type and quantity of working fluid, pipe diameter, pipe length, and ratio of cooled surface to heated surface, the length of the adiabatic zone between heated and cooled sections, heat flux and operating temperature. Evaporator and condenser of the loop thermosyphon can be made of carbon-steel, copper or aluminum. Propane, R 134a, R 600, ammonia or water can be used as working fluid. Water is the best working fluid if copper can be applied. In order to establish heat transfer correlations for the application in the design program for the loop thermosyphon heat exchanger, regression analysis could be applied to experimental data for heat transfer coefficients in evaporator and condenser.

Typical loop thermosyphon with the flat evaporator is shown on fig.4. This thermosyphon is capable to transport heat flux near 100 W at the temperature of the adiabatic zone equals to 100 °C. The condenser is cooled by water circulation. The thermal resistance of thermosyphon R is 0.03 K/W.

*2.4 Loop heat pipes with noninverted meniscus*

Loop heat pipes are more flexible to compare with loop thermosyphons due to its insincerity to the gravity field. Typical LHP for PEMFC with optimal heat flow rate 800 W at the working temperature near 80 °C is shown on fig.5.

LHP with non inverted meniscus of the evaporation designed and tested in the Luikov Institute. It is made from copper and has the wick performed by copper sintered powder. The working fluid is water. The typical maximum heat flow rate of such evaporator is near 1500 W, the thermal resistance of the evaporator is 0.06 K/W. The length of the evaporator is 70 mm, width is 60 mm and thickness is 12 mm. The wick porosity is more than 45% and the effective thermal conductivity of the wick is 40 W/m K.

*2.5 Pulsating heat pipe panels*

Aluminium (multi-channel) heat pipe panel (fig. 6) with propane as a working fluid ia another alternative to the conventional heat pipe for FC stack cooling [10–12]. Pulsating heat pipe (PHP) is one of several oscillatory thermal transport cycles under development that are receiving attention as a potential semi-passive, high-power, high flux heat transport device. The PHP is unique because of it is capable produce driving pressures in excess by many mechanically pumped loops. Capillary forces do not limit the PHP and it is capable to transfer high heat loads over long distances and against significant resistance (i.e. gravity, small tube diameters, etc.).

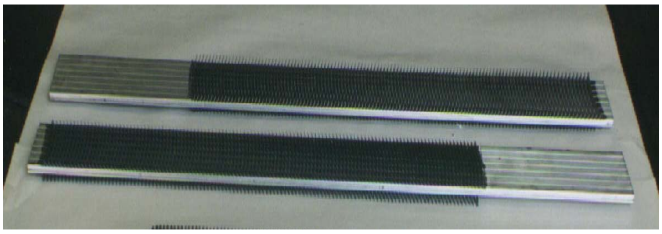

Fig. 6. Aluminum pulsating heat pipe panel with mini channels inside and mini fins on the outer surface

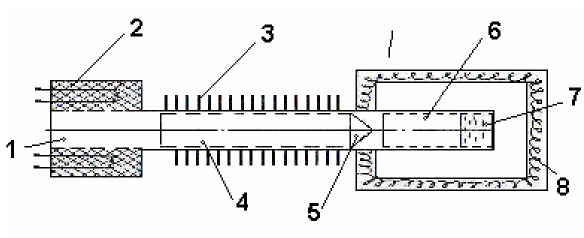


Fig. 7. Sorption heat pipe: 1 – vapor channel, 2 – sorption structure, 3 – finned surface of heat pipe evaporator/condenser, 4 – porous wick, 5 – porous valve, 6 – low temperature evaporator with porous wick, 7 – working fluid, 8 – cold box with thermal insulation.

The main parameters of flat heat pipe panels developed in the Luikov Institute, Minsk are: HP width is 70 mm, HP height is 7 mm, HP length is 700 mm, evaporator length is 98 mm, condenser length is 500 mm, mass is 0. 43 kg. HP thermal resistance is 0.05 K/W, evaporator heat transfer coefficient is 8500 W/($m^2$·K), condenser heat transfer coefficient is 2500 W/($m^2$·K). Working fluid (hydrocarbon) dynamic movement is stable with liquid filling ratio near 0.6 of the heat pipe volume.

*2.6 Sorption heat pipes*

The sorption heat pipe (SHP) combines enhanced heat and mass transfer in conventional heat pipes with sorption phenomena of a sorbent bed. The original design of such a sorption heat pipe was patented in USSR in 1992 [12]. Sorption heat pipe could be used as a sorption heat transfer element and be cooled and heated as a heat pipe [13].

The sorption heat pipe (fig.7) has a sorbent bed (adsorber/desorber and evaporator) at one end and a condenser and an evaporator at the other end. Sorption heat pipe have a sorbent bed (adsorber/desorber and evaporator) at one end and a condenser + evaporator at the other end. Traditional two-phase thermal control system for FCs is sensitive to the vehicle acceleration and vibration. Sorption heat pipe thermal control is efficient for such cases.

The solid sorption cooler begins to function, when cooling possibilities of the conventional heat pipe are exhausted. Sorption heat pipe cooler has some advantages comparing with conventional loop heat pipe coolers in the case, that:

- requires operation in large accelerations,
- requires higher pumping capability, require more intense heat transfer in the evaporator,
- requires operation of sorption heat pipe evaporator colder than the environmental temperature

The heat output of SHP developed in the Luikov Institute is about 1000 W (water), the thermal resistance of the evaporator is 0.03 K/W, pressure drop is 200 mbar.

## 4. Conclusions

Heat pipe concept as a thermal control system for micro/mini fuel cell is a powerful tool of FC efficiency increasing. Micro/mini heat pipes are considered as advanced thermal control for mini fuel cells with power generation of 10–100 W. Loop heat pipes, pulsating heat pipes and sorption heat pipes are suggested as an advanced thermal control system for portable mini fuel cells with power generation higher than 100 W.

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