Pulsating heat pipe panels

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Abstract

Different types of flat heat pipe panels (pulsating, "spaghetti") are developed oriented on the sorption refrigerators and heat pumps application as thermal control systems. The liquid-vapor system formed in the capillary channels inside the heat pipe panel is capable of generating self-sustained thermally driven oscillations. Heat pipe panel can be also considered as a micro channel heat sink for the electronic components cooling, when the electronics chips could be effectively cooled by means of forced convection of one and two –phase flow. Thin layer (1-2 mm) of the sorbent composite (for example, Al_2O_3 + salts) between mini-fins on the outer side of the heat pipe panel ensures an advanced heat and mass transfer during the cycle adsorption/desorption. A sorption panel system for cooling buildings was developed, working with an adsorption-refrigeration unit, the evaporator of which is the panel itself.

KEYWORDS
Pulsating heat pipe, heat pipe panel, sorption technology

Introduction

Flat heat pipe panels (HPP) have attached substantial attention last years due to their advantages over conventional cylindrical heat pipes, such as geometry adaptation, ability for much localized heat dissipation and the production of an entirely flat isothermal surface. Flat HPP can be applied as bathroom floor heaters, ceiling cooling elements [1], as a component of sales cabinets for chilled and frozen products [2], and as cooling systems for electronic devices and space vehicles [3]. Pulsating HPP are considered as interesting alternative to conventional cylindrical heat pipes [4]. Recently flat HPP are becoming very efficient as thermal control devices for water sorption coolers and air-conditioning systems due to the low pressure inside the envelope, when porous sublimator heat exchanges are used instead of evaporators. Water is a most welcomed fluid for modern air-conditioning, heat pumping and refrigeration. So HPPs for water sorption technologies are really exciting. HPP for sorption heat pipe are considered as a combination of a HPP and solid sorption cooler on its surface with some specific interaction between these elements [5]. Another alternative to conventional heat pipe is an aluminium, or stainless steel (multi-channel) HPP with propane, or alcohol as a working fluid to cool the low temperature sorbers of heat pumps and refrigerators [6, 9]. The goal of this work was the development of HPP with sorbent shin covering on its surface to integrate such a panel in the sorption refrigerator.

Heat pipe panel design.

HPP is considered as a system including some channels of capillary dimension, which are bent in a serpentine manner and the ends are joined. This device is filled partially with working fluid. The flow instabilities inside of this device are produced due to the heat input in one part of it and heat output from the another part by heating multi-channels (H = 2mm, L = 5 mm) at one end and simultaneously cooling the other end thus resulting in pulsating fluid. This heat input and output stimulates a heat transfer, as a combination of sensible and latent heat portions. The flow instabilities are a superposition of various underlying effects. In our experiments as an experimental set-up an aluminum multi-channel panel was chosen, partly filled with propane. The main parameters of flat aluminium heat pipe panel (Fig.1), developed in the Luikov Institute are: HPP width-70mm, HPP height- 7 mm, HPP length –700 mm, evaporator length-98 mm, condenser length – 500 mm, mass- 0, 43 kg. Propane was applied to fill the HPP and it is interesting as a working fluid with the point of view of its compatibility with all heat pipe envelopes and wick materials (aluminum, steel, stainless steel, copper, AL_2 O_3, et).

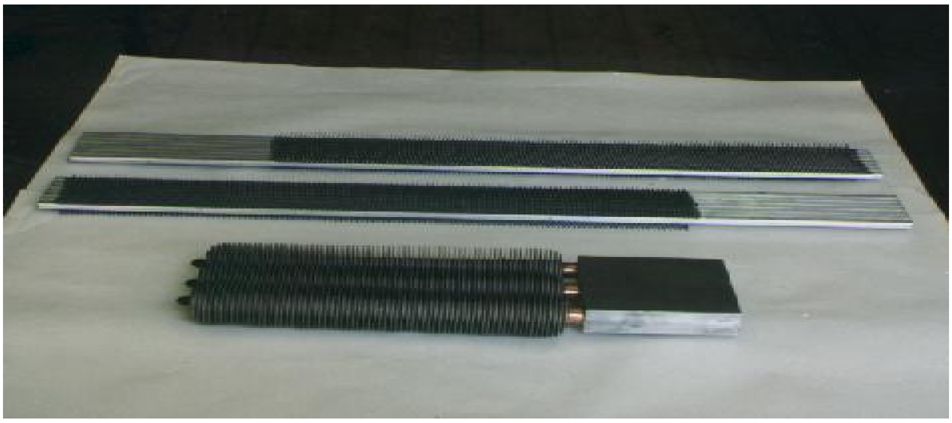

Fig.1. Aluminium multi-channels pulsating heat pipe panel with propane as a working fluid

An experimental set-up for HPP testing is shown of Fig.2. All experiments with HPP and HPP, covered with sorption layer are performed on this experimental rig.

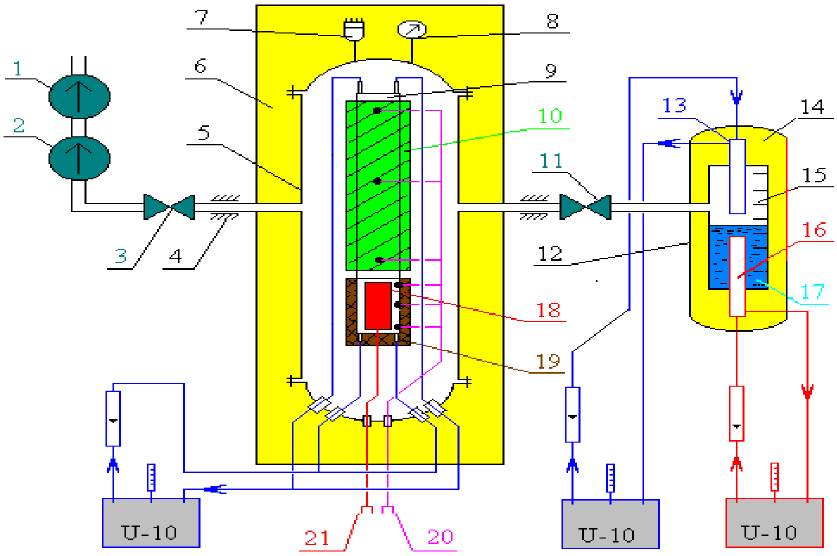

Fig. 2 1,2 - vacuum pumps ; 3 – valve;4 – system to incline the set-up; 5 – vacuum chamber envelope; 6 – thermal insulation of a chamber;7 – pressure gauge; 8 – vacuum recorder; 9 – HPP; 10 – sorbent bed; 11 – valve; 12 – evaporator/condenser; 13,16 – heat exchangers;14,19 –thermal insulation; 15 – level of liquid indicator;17 – water volume;18 – electric heater; 20,21 – electric contacts.

This experimental rig has some possibilities to make all the measurements of the heat transfer in the evaporator and condenser HPP, HPP thermal resistance and critical heat flows with its different orientation in space. The longitudinal cross of the HPP is shown on Fig. 3

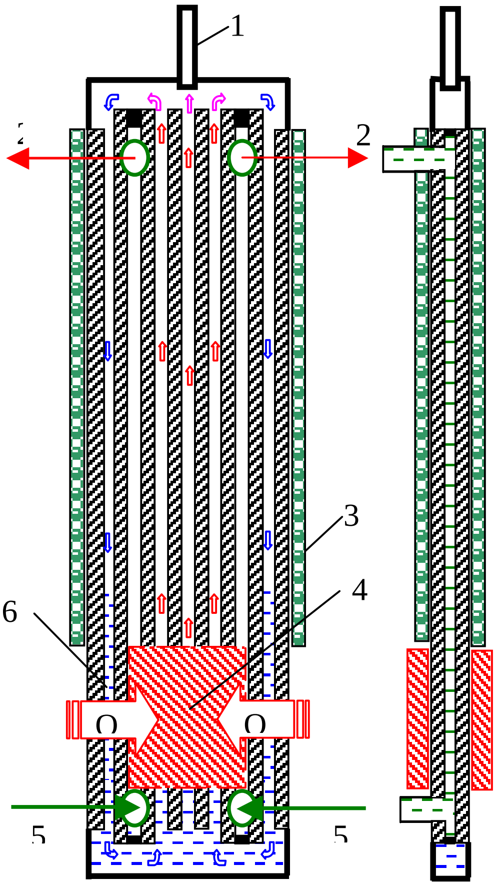

Fig. 3 Multi channel flat aluminum HPP. 1 - liquid charging input; 2 - liquid cooling output; 3 - sorbent bed integrated between fins;4- heat load; 5 - liquid cooling input; 6 - working fluid

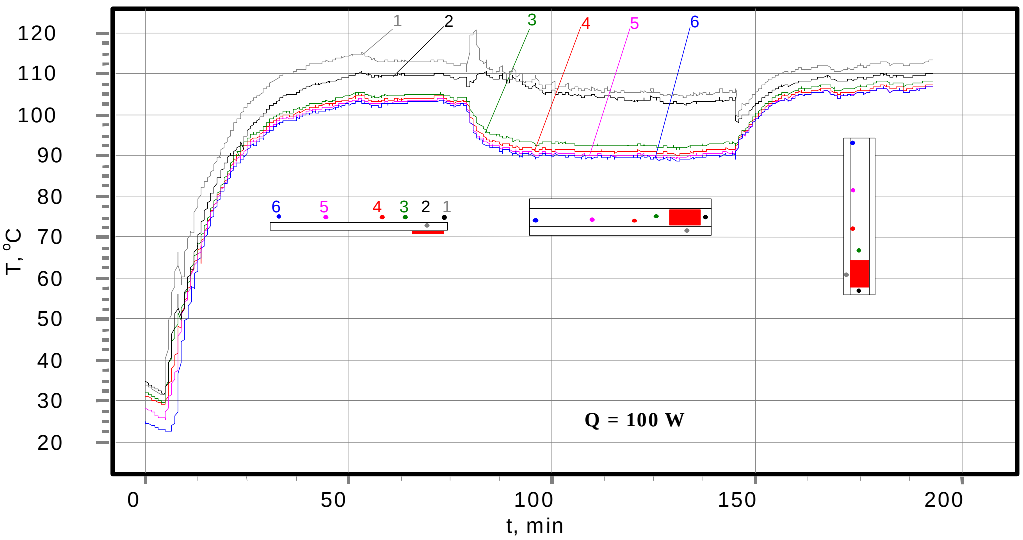

Fig.4 Temperature field distribution on the surface of HPP (evaporator, transport zone and condenser) for different HPP orientation in space. The working fluid is propane. The electric heater is shown as a red color rectangular.

The influence of the gravity field on HPP thermal resistance and temperature field distribution along the panel is shown on Fig.4.

The experiments with HPP of different orientation in space testify the influence of the gravity forces on the heat transfer in the evaporator and condenser. The liquid-vapor system formed in multi-channel closed panel is capable to generate self-sustained thermally driven oscillations. The bubbles appearance in the evaporator and the bubbles collapse in the condenser are the reason of the fluid motion along the HPP channels; it means the pumping action is available when the bubbles are present and are used as compressing elements (like rubber balls). The thermo-hydrodynamic forces are the reason to ensure self-sustained thermally driven bubble pumping in the HPP channels like a mechanical mini-pump. The data acquisition system connected to PC was used in order to record the time evolution of the temperature and mass flow of the heating/cooling fluids and of the temperature and pressure of the sorbent bed, condenser and evaporator. The accuracy of the temperature, pressure and mass flow measurement devices were respectively 0.1°C, 0.1 mbar and 0.1 l/min. The temperature interval was -10^{0}C - + 110 ^{0}C, the pressure interval – 3, 5 – 13, 8 bars. HPP thermal resistance R=0.05 K/W, evaporator heat transfer coefficient α = 8500 W/m^{2}K, condenser heat transfer coefficient α = 2500 W/m^{2}K.

“Spaghetti” Heat Pipe

The small diameter (3 mm) bendable SS “spaghetti” heat pipe is made as wire-on-tube heat transfer system and is similar to closed-loop pulsating (oscillating) heat pipe, but has a compact condenser and large surface finned (wire-on-tube type) evaporator. The tube is made from steel and has a steel wire fins on its surface. The wire-on-tube type heat exchanger now is in often use in small refrigerating devices. An example of steel “spaghetti” heat pipe filled with ammonia is shown on Fig.5, 6 [10]. “Spaghetti” heat pipe panel is disposed inside the refrigerator chamber in such a way that food can be kept within the refrigerating temperature range as uniformly as possible. “Spaghetti” heat pipe is thermally linked with an evaporator of the sorption refrigerator (“Spaghetti” condenser) and has a good thermal contact with this evaporator. “Spaghetti” heat pipe panels are used as uniform temperature sheets inside the cold chamber connected with a cold store unit (sorption refrigerator, cold accumulator, or dry ice box). “Spaghetti” HPPs have no capillary structure inside and are functioning under the oscillating motion of the two-phase ammonia due to a big difference between the liquid and vapor density under the heat load. The driving force of "spaghetti" heat pipes is the pressure force generated by the liquid boiling at high temperature zones (lower part of the refrigerator cabinet), non-equilibrium state between vapor and liquid and vapor bubbles collapse in the upper cold part of the panel. The velocity of the bubble rises through the liquid in a pipe is governed by the interaction between buoyancy and the other forces acting on the bubble. If the viscosity of the vapor in the bubble is neglected, the forces besides buoyancy are those from liquid inertia, liquid viscosity and surface tension. Vapor bubbles push the liquid plugs to the cold part of the unit where vapor bubbles collapsed with the increasing of pressure difference between vapor and liquid. The temperature of the “spaghetti” evaporator and condenser sections was controlled during the experiments at – 30^0 up to 30 ^{0}C respectively. The data acquisition system guaranteed the ± 0.1 ^{0}C accuracy of the temperature measurements. Chromel - alumel thermocouples attached to the evaporator and condenser surface were used. There were three points on the evaporator, two points on the condenser. The experimentally determined “spaghetti” heat pipe thermal resistance is R = 0.006 K/W.

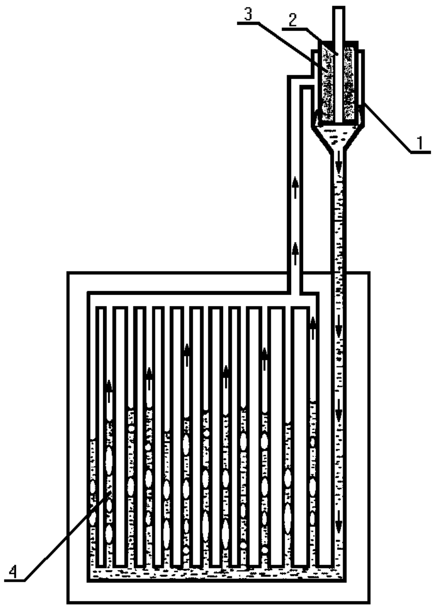

Fig. 5. Schematic of “spaghetti” heat pipe panel; 1 – condenser of the heat pipe, 2 – evaporator of the adsorption refrigerator, 3 – porous structures, 4 – heat pipe evaporator

Fig. 6. "Spaghetti" heat pipe panels inside the refrigerating chamber

HPP with a thin layer of sorbent bed on its surface.

Application of thin coverings of Al_2O_3 , silica-gel, active carbon and zeolite saturated with salts ($CaCl_2$) as solid sorbent bed and water, methanol, or propane/butane as refrigerant has been recently proposed for application in sorption machines for cooling [4, 7 - 8], Table 1.

Table 1 Parameters of different sorbent composites

Sorbent bed composition	Coefficient of the permeability, **$Kx10^{13}$, m^2**	Maximum pore diameter, **d_{max}, mm**	Medium pore diameter, **d_{av}, mm**
γ-Al_2O_3+ Al	2,8…5,5	41…77	21…37,8
Zeolite+Al	5,6…6,6	58…89	26…38
Silica – gel + Al	1,9….4,0	49…84	20…35

Such sorbent beds inserted into mini-fins of finned stainless steel, or aluminum panels are the most convenient sorbers for refrigeration/heat pumping, using water, methanol, butane as working fluids.

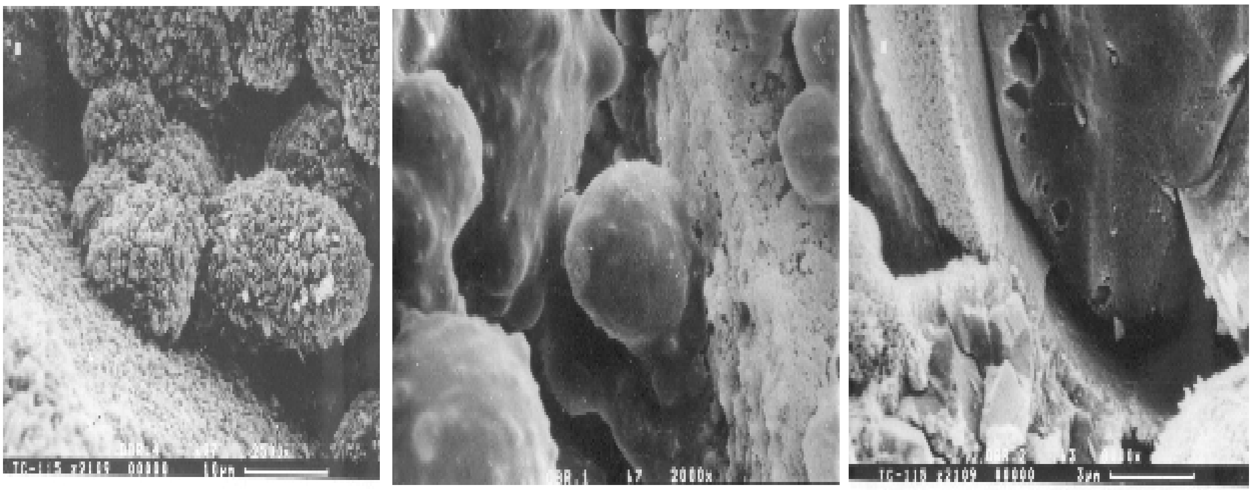

Fig. 7 The sorbent bed microstructure, visualized with high resolution scanning microscope.
Silica gel – HTS (x2500) γ-Al_2O_3+ Al (x6000) Zeolite - HTS (x2000)

Adsorbent in the form of a thin coating on a heat exchange surface of HPP ensure some advantages: 1.Direct contact between adsorbent and metal results in high heat transfer rates.
2. Mini-fins are performed on both outer surfaces of HPP. Adsorbent composite (Al_2O_3 + $CaCl_2$) is packed into spaces between HPP fins. The coupling between topping and bottoming sorption cycles is provided by heat pipes. The direct coupling ensures the operating temperatures in both cycles more favorable from a thermodynamic point of view since temperature drops due to the thermal storage can be avoided. The second advantage of heat pipe coupling of sorption cycles is the heat recovery between the high temperature cycle and low temperature cycle with good thermodynamic efficiency. HPP with Al_2O_3 , silica-gel and zeolite sorbent bed on its surface were performed and tested to determine such its parameters as: kinetics of water sorption, water sorption capacity, coefficient of permeability (1.9 - 6.6 10^{13} m^2), maximum pore diameter (41-89 μm), medium pore diameter (20-38 μm) , etc. The sorbent bed microstructure, visualized by scanning microscope, was determined for such compositions as γ -Al_2O_3 + Al, Zeolite + Al, Silica gel + Al, Fig.7. The mass ratio sorbent bed/heat pipe is near 0.25. The most important dynamic properties of such composites (porous host material + salts) are the thermal conductivity, specific heat and kinetics of water adsorption. Such composites can effectively operate with adsorption temperature 30 - 40 ^{0}C and regeneration temperature 90 - 95 ^{0}C. Objectives of this research program is an assess the advantage of porous composites in the form of a thin coating on a heat pipe surface, such as: study the value of adsorbent coated heat pipes compared to loose porous materials, the reduction in capital cost, short cycle time, high heat and mass transfer coefficients, availability of low-grade waste heat in industrial, or automotive applications. Direct thermal contact between adsorbent and metal fins results in high heat transfer rates and increase of the COP of the system. The results of comparison of porous composites (silica-gel + $CaCl_2$) with silica-gel in loose form give two time (1000 - 1100 W/kg) increasing of specific cooling power.

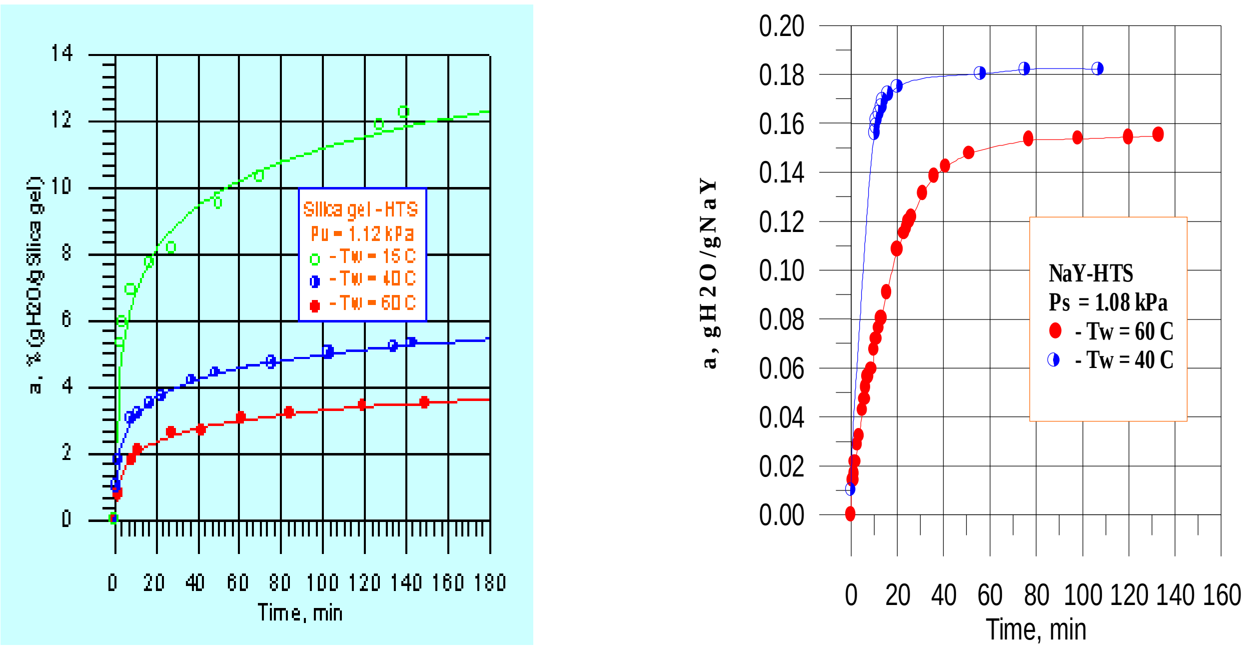

Fig. 8 Water adsorption rate on zeolite and silica-gel sorbent bed (HTS), disposed on HPP surface as a function of time

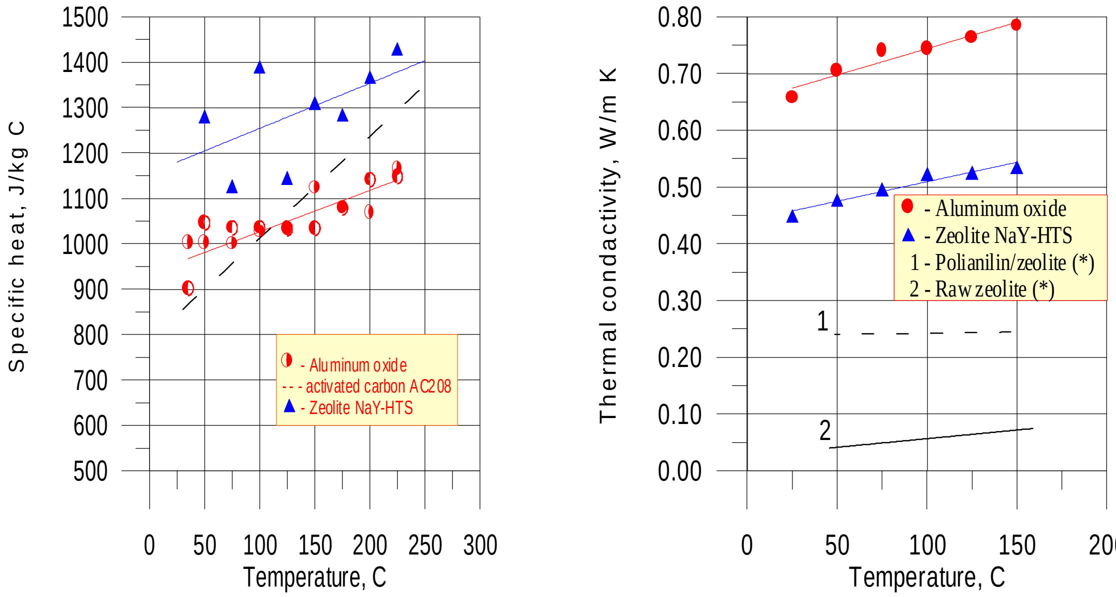

Fig. 9 Specific heat and thermal conductivity of Al_2O_3, activated carbon and Zeolite NaY-HTS as a function of temperature.

Silica-gel HTS and zeolite NaY HTS composites were obtained by the method of the hydro-thermal synthesis of pure particles of aluminum with silica-gel and zeolite NaY mixture. HTS composites were performed with its further pressurizing and heating in the drying chamber. All necessary thermal properties of these sorbent composites were analyzed, Fig.9 and a conclusion were done, and that the thermal conductivity of HTS composites is higher to compare with original materials (silica-gel, zeolite).

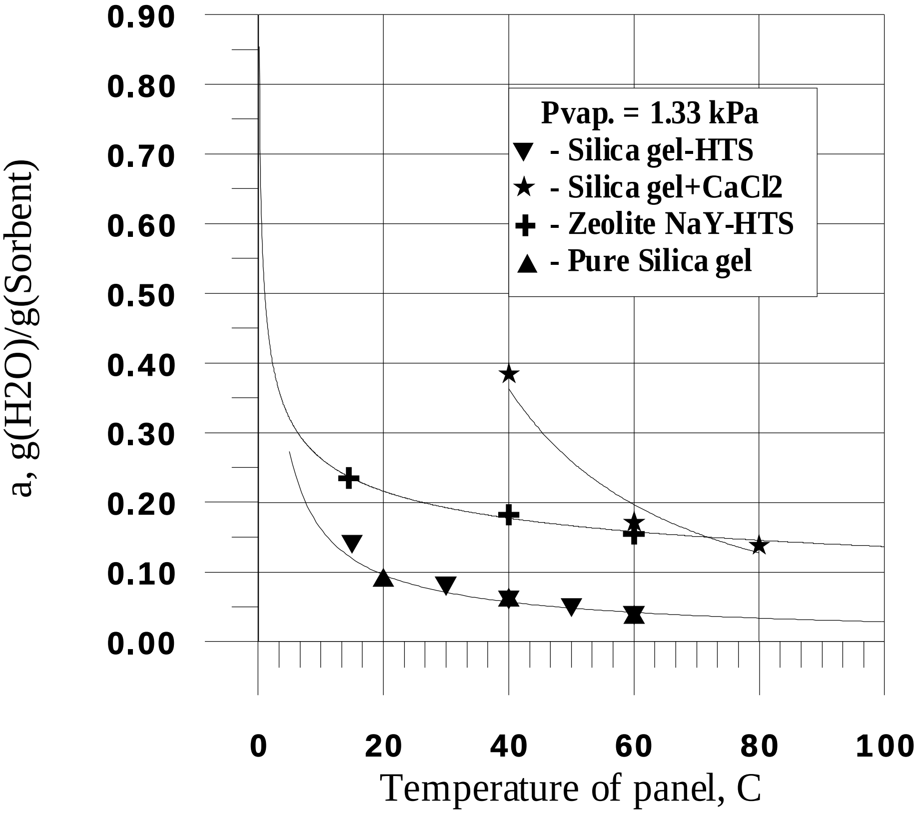

Fig.10 Isobares of water vapor sorption on silica-gel HTS, pure silica-gel, zeolite NY-HTS and silica-gel with $CaCl_2$ in loose form

The above mentioned Figures 8-10 represent the experimental data on compounds made by the hydro-thermal synthesis (HTS).The thermodynamic equilibrium with water vapour has been measured for silica-gel, zeolite and Al_2O_3 sorbent beds. It was shown that water sorption properties of these materials can be controllably modified. Among the measured dynamic properties of compounds are the thermal conductivity, specific heat and kinetics of water adsorption.

Conclusions

Pulsating heat pipe panels (HPP) were tested to be sure they are useful for the electronic components cooling and sorption machines thermal control. Pulsating HPP are potentially cheaper than conventional wicked heat pipe panels. Pulsating HPP are convenient with the low pressure working fluids like water, alcohol and some hydrocarbons. The physical understanding of the two-phase heat and mass transfer under the different heat loading till now is not clear enough to get a good theory of these devices. Semi-empirical correlations available now in the literature are not still good enough for HPPs designing and manufacturing, and more fundamental modeling approach is necessary.

Pulsating heat pipe panels with a thin sorbent bed covering on its fins are convenient for the thermal control systems of refrigerators and heat pumps. A new technology of the sorbent bed performance (silica-gel, zeolite and Al_2O_3 composites) with the help of hydro-thermal synthesis are used to get some sorption HPP with water as a working fluid.

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