EXPERIMENTAL MODELING OF PULSATING HEAT PIPES

Konev S.V., Aliakhnovich V.A., Koneva N.S.
A.V. Luikov Heat And Mass Transfer Institute
Address: HMTI, 15, Brovka St., Minsk, 220072, Republic of Belarus
Tel: (375 17) 284 15 17, Fax: (375 17) 232 25 13; Email: konev@hmti.ac.by

Abstract

Designs of the closed pulsing heat pipes of both serpentine and over pressed types are developed. Some heat pipes are created for visual study of two-phase flow inside channels. Ethanol, freons and water were used as heat-carriers. The range of parameters of effective action of heat pipes is determined. The high efficiency of heat transfer is shown at small heat fluxes.

The results of testing are putted in a basis of the creation of the oscillation heat pipes (OHP) both for heat exchangers and solar collectors. The features of application of pulsing heat pipes in particular for thermal control of electronic, optical and mechanical instruments are considered.

A series of numerical experiments on water as working medium is carried out to predict a degree and range of parameters, where it is possible to observe enhancement of heat transfer. The experimental installation allows to measure parameters and to process under the developed program in real time. Researched samples of heat pipe are made on glass capillary tubes open and closed, including both nonlinear form and loop (14 alternations). It allowed making a video survey of process of growth, expansion and pulsation of bubbles. The diameter of a capillary had size from 100 micron up to 3mm.

KEYWORDS

Oscillating heat pipe, visualization, solar collector, heat exchanger.

INTRODUCTION

Recently the attention has amplified to study non-stationary heat and mass transfer processes, for example, pulsing modes of a heat transfer in heat pipes (HP).

One of the ways of efficiency increases of heat transfer is using the oscillating capillary loop heat pipes. These oscillating modes are the reason of enhanced heat transfer coefficients in comparison on stationary state modes. It is noted, that the pulsations in heat pipes were investigated earlier, however only H. Akachi used pulsations in narrow channels for heat pipes and he closed the process into circle [2]. Now there are many works on open pulsation heat pipes, including Luikov Heat and Mass Transfer Institute investigations for both a cryogenic and average temperature [3,4].

The oscillating capillary heat pipe differs from usual loop HP by the heat-carrier supply in evaporator, which occurs by fluctuation of vapor phase pressure. The wick cap in heat pipe is absent and that provides the simplicity and cheapness of design.

The explanation of enhancement heat and mass transfer in an evaporation/condensation cycle is offered with considering a extending pressure under the action of the external capillary meniscus. The advantages of action of heat pipe are shown at organization evaporation in the top part, i.e. they’re where an essential influence of gravitational field. Physically it is possible to explain by moving of the boiling curve Nukiama in area of smaller superheating. The analytical equations and the calculations have shown, that the mode of a pulsation takes place in a capillary heat pipe only at presence not less than two concave meniscus, and the second can be organized by other bubble or free liquid surface. Three computer programs are developed for calculation of influence of thickness of a capillary and inclination of HP to horizon, in view of temperature dependence thermal properties of working liquid.

The tests of thermal and optical parameters are carried out for comparison with theoretical model.THE VISUAL INVESTIGATION OF OSCILLATING HEAT PIPE

The first stage was the experimental observation of heat and mass transfer processes in oscillating capillary HP. For processes visualization the chamber shooting was used in experimental equipment. Schematic setup is shown in fig. 1. Electrical heater 5 supported the required temperature of operation conditions. Heat transfer device based on oscillating capillary heat pipe, was made of a heat-resistant glass. The construction scheme and photo of device is shown on fig. 2.

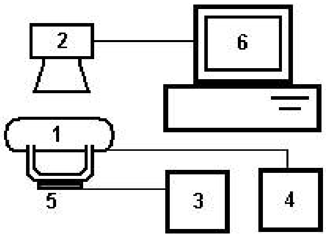

Fig. 1. The scheme of setup: 1-oscillating heat pipe; 2-camera; 3-current supply ; 4- thermal gauge; 5 - heater; 6 – computer

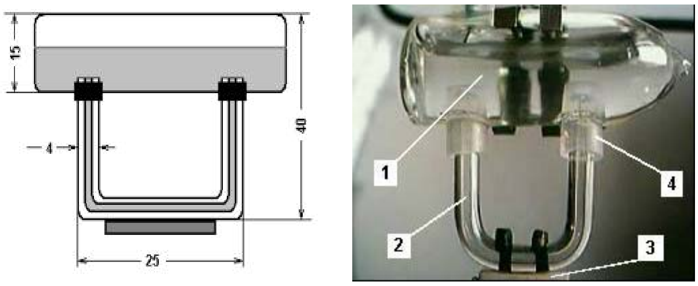

Fig. 2. The scheme and photo of heat transfer device: 1 - compensatory chamber; 2- capillary channel; 3 - heater; 4 - silicone sealant.

The device consists of capillary channel, compensatory chamber and heater. Before the experiments the chamber was filled with water amount and then sealed by the capillar with using silicone sealant. The experiments were carried out with two different water volumes in chamber. The first experiment was carried out with the completely filled chamber, the second - with half of volume. In addition the series of experiments with different diameters of the capillary channel from 0.1 mm up to 2 mm was carried out.

The mechanism of pulsations of water and bubbles in capillary channel with different diameters were studied. The experimental observations have shown, that pulsations are less intensive, or are absent at all if the diameter of the capillary channel less than 0.5 mm. Therefore in this paper the experimental results for diameter 1мм are given.

The first experiment was carried out in a simple mode. The compensatory chamber was half filled with distilled water and then with the help silicone sealants sealed by a capillar, as shown in fig. 2. When the voltage on electrical heater varied the evaporation section of capillary loop was heated up. With the achieving of boiling temperature on capillar internal walls there were the nuclei as shown on fig. 3 (a). Their amount depends on properties of glass, from which the capillary is made. The nuclei that have reached the certain size extend sharply. The growth of a bubble occurs mainly in one of bends of capillar, as shown in a fig. 3 (b). There are the nuclei after the bubble is collapsed, and the cycle repeats again with only one difference that the next bubble extends in other bend of the capillar as shown on fig. 3 (c). Thus the serial pulsations to the left and to the right were observed. The frequency of these fluctuations increases with increasing the water temperature in compensatory chamber.

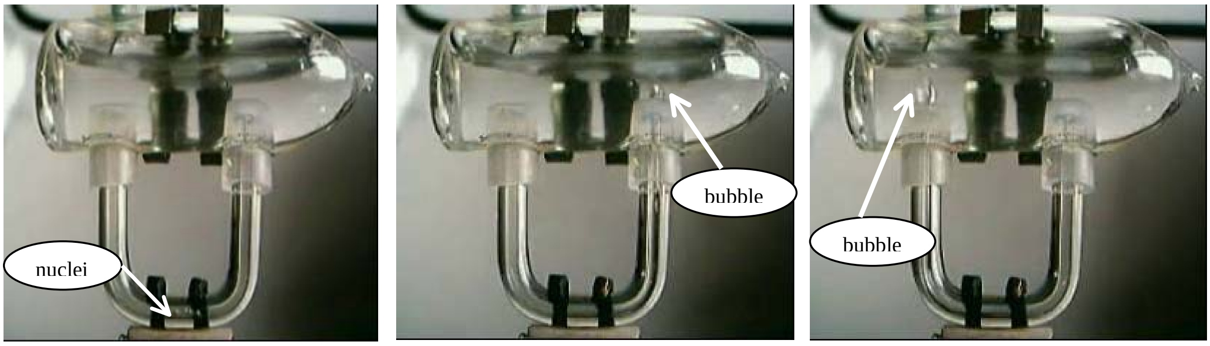

Fig.3 (a, b, c). The various stages of work of oscillating loop: a – the initial stage, b –in one bend, c – bubble growth in opposite bend.

The difference of next experiment from the above mentioned consists in piece of thin steel wire with diameter 0.3 mm, which was placed in one of the bends of capillar as shown in a fig. 4 (a).

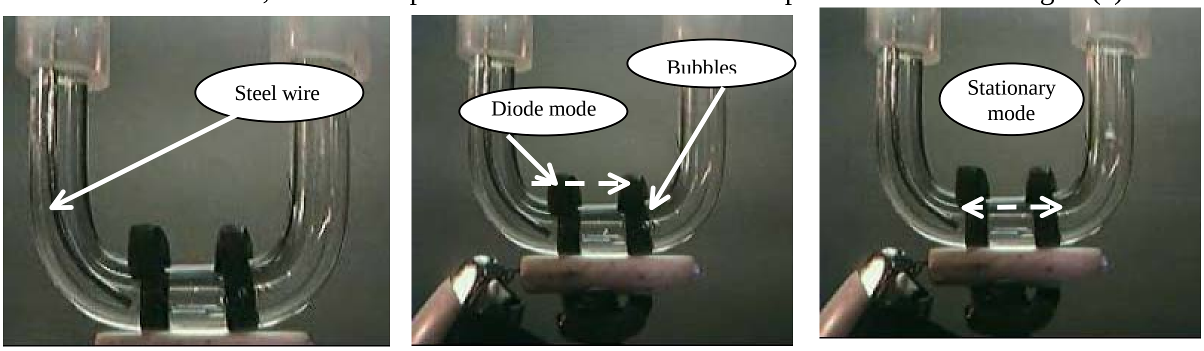

Fig.4 (a, b, c) The various stages of work of oscillating loop: a – initial stage with wire, b – the right bent activation – diode mode, c – quasi stationary process with activation of both bends.

Thus, the heterogeneity condition was created in pulsations area. The existence of wire changes the capillary forces, which influence on a liquid column surface in capillary channel and also changes the hydrodynamic characteristics. After these changes the behavior of steam bubbles and liquid column has changed. Firstly, the additional nuclei have formed in evaporation part and the pulsations frequency has increased. Secondly, as shown on fig. 4 (b), the all bubbles extended only in one direction opposite to that direction, where there is steel. The frequency of pulsations was increased via the temperature of water. However at certain temperature of a pulsation disappeared, and the vaporization process passed in stationary mode as shown on fig. 4 (c). The evaporation surface in heating zone was kept motionless and the surface of condensation zone has fluctuated little.

The researches in the field of creation unidirectional heat transfer devices - thermal diodes of a loop type of the small sizes allow generating the scientific bases for creation of tiny systems of cooling for maintenance of thermal modes for heat load elements. The intensive cooling will allow developing the wide range of devices of microelectronics, semi-conductor lasers, chips of computer processes etc. Due to the small size (0,2 - 1,5 mm) such loops can be placed directly under the heat output element crystal - in input pad of the device and to disseminate the heat from thermal load elements.

Development of early studies and consists in utilization of principle of pressure drop in capillaries with different radiuses with varying values during the section length. If to such conic loop capillary partially filled with a liquid to move in a narrow part a heat flow, in this place the steam bubble will generate, transferred a flow in the party of greater radius. The vapor micro bubble in conic part of capillar will move the liquid column to part with bigger radius and evaporation-condensation cycle will support it in a stationary or pulsing mode. Thus, there will be the unidirectional diode circulation of a liquid in closed circle.

The problems of cooling strongly limits development of microelectronics and first of all of computer engineering. The development of technology for creation of the processors connected to creation of chips with sharp increased frequency, small dimensions and increased heat output.

Therefore use and realization of unidirectional two phase cycle as the closed capillar, placed in a heat-stressed zone of the chip, will allow essentially to lower its temperature and to improve the operational parameters of electronic engineering, for example portable computers.

STUDY OF SOLAR COLLECTOR ON OSCILLATING HEAT PIPE

An oscillated heat pipe in research is made of rather long and thin sealed pipe.

The experiment purpose is the study of optimum operation modes of pulsing heat pipe with enough large sizes and the opportunity of such pipe using as the absorber of solar collector.

The comparative analysis of heat output flow in dependence for various types of working liquid and for filling ratios 50 %, 66 %, 72 %. The evaporator cooling is occurred by the natural convection, thus the importance of factor of heat exchange between the condenser of heat pipe and environment was estimated and was accepted equal 9 W/m^2 ^{0}C. The peculiarity of operation of pulsing pipe was also investigated with dependence on temperature differences and filling ratio.

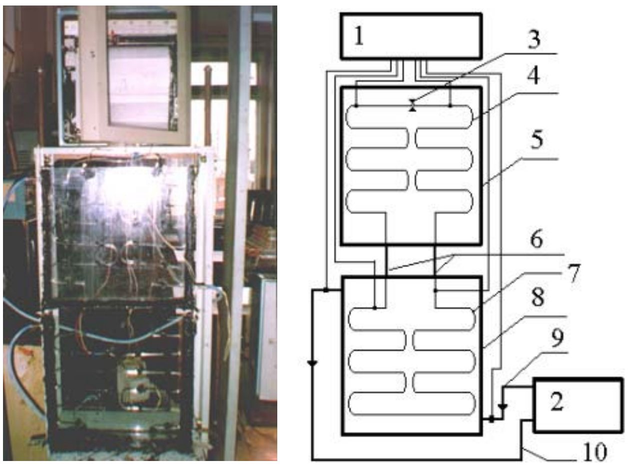

Fig. 5. The photo and scheme of setup for visual investigation of pulsing heat pipe:
1 - temperature recording instrument;
2 - thermostat; 3-refueling valve;
4 -condenser; 5- cooling volume;
6- connecting pipes; 7 -evaporator;
8 - heating volume; 9 - pipe for hot water supply, 10 - pipe for water supply.

The scheme of experimental setup for visual observation over the pulsing heat pipe is shown in fig. 5.

The thermocouples and electronic potentiometer were used for temperature measurements. For visualization the glass heat pipe with length 6 meters and external diameter 4.6 mm and internal 2.1 mm was chosen. The geometry of a pipe satisfies to operating conditions with use the freon 113 and ethanol. Evaporator and condenser have the identical configuration and geometrical sizes. Heat input to evaporator of heat pipe is carried out in transparent chamber at the expense of heat transfer to water, which is heated up to certain temperature with thermostat. The heat pipe condenser was fixed similarly, but the cooling was occurred by air convection.

The new solar collector model with pulsing heat pipe for some operation conditions at negative temperatures were developed. The design is offered with large length of each shoulder, at hairpin bend. Benefit of design is in a minimum number of transitive elements between evaporator and condenser. The

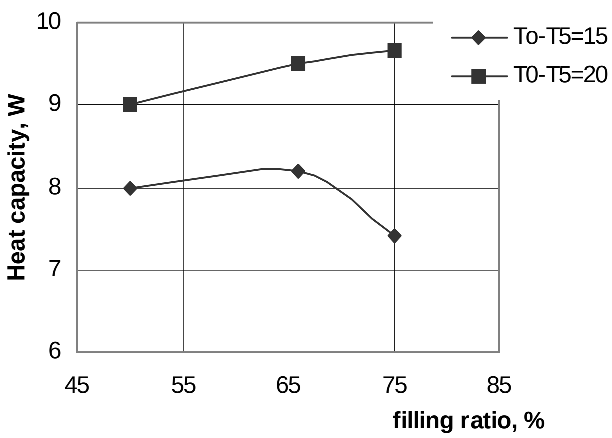

Fig.6. The dependence of heat flow from filling ratio for ethanol HP.

horizontal location of the knees worsens the gravitation influence on return of condensate.

The experiments were directed on study of the characteristics of a pulsing heat pipe in different operating parameters depending on temperature difference in evaporator and condenser. On the external surface of heat output/input zones of heat energy the boundary conditions of the third kind (in the evaporator zone the heat exchange with water and in condenser zone the heat exchange with air/water). The results of experiment for ethanol for various filling ratios are shown in fig. 6.

It is shown for ethanol, the transferred heat flow is more than for Freon 113 and the pulsing heat pipe with ethanol operated more effectively at temperature difference, than for Freon 113.

The amount of liquid phase of working fluid is essential influenced on operation parameters of pulsating heat pipes and on heat flow. Therefore, the series of experiments was carried out for various filling of ethanol.

For ethanol curve of dependence of transferred heat flow have the extreme character with maximum between 55 % and 65 %.The carried out experimental researches allow to make a conclusion about the opportunity of effective operating of pulsing heat pipes on ethanol and using as the base element the low temperature solar collectors down to negative temperatures.

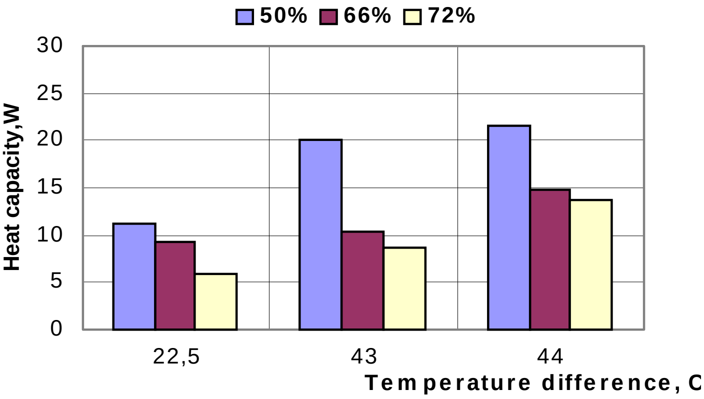

Fig.7. The dependence of output heat flow from temperature differences for ethanol HP.

The number of sections of pulsing heat pipe is determined from necessary power of solar collector. The tested pulsing heat pipe consisting from two shoulders, allowed to transfer the heat flow 10÷30 W. If the solar collector power is 500 W than it's require locating on absorber about the 20 bends. Between the evaporator and condenser the sections can be collected in one beam.

DEVELOPMENT OF LIQUID-LIQUID OSCILLATING HEAT PIPE EXCHANGER

The model of liquid-liquid heat exchanger on oscillating heat pipe is created for determining of advantages and insufficiencies of OHP. For the visualization of process the experimental model was made of glass (container) and polyvinyl heat pipe loop (Fig.8).

Heat exchangers were mounted vertically. The sections of heat exchanger were supplied with water from two thermostats. The temperature of water at the output of section was maintained at different levels. Sections are divided by the watertight porous rubber with thickness of 20 mm for ensures the thermal insulation separation. There were determined the regimes of the beginning of the oscillating regime, sizes and frequency of bubbles. The heat flow was calculated by calorimetric way.

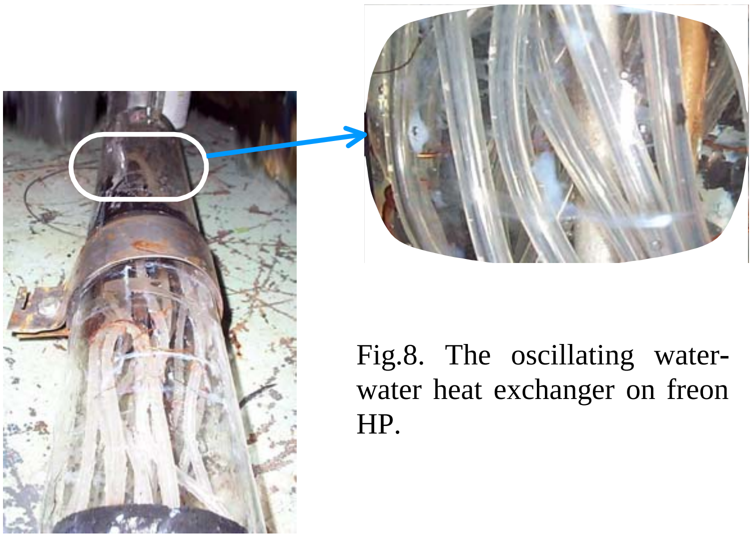

Fig.8. The oscillating water-water heat exchanger on freon HP.

The transferred heat flux was 280 W if the temperatures difference was 40 ^{0}C. The parameters of heat exchanger are next:

Container	Closed loop heat pipe
Length: 0,5 m	Length: 7 m
Diameter: 0,07 m	External diameter: 5 mm
Material: glass	Internal diameter: 3 mm
Intertube board: rubber	Bends number: 14
Number of sections: 2	Bend length: 0,48 m
Heat agent: water	Heat agent: F113

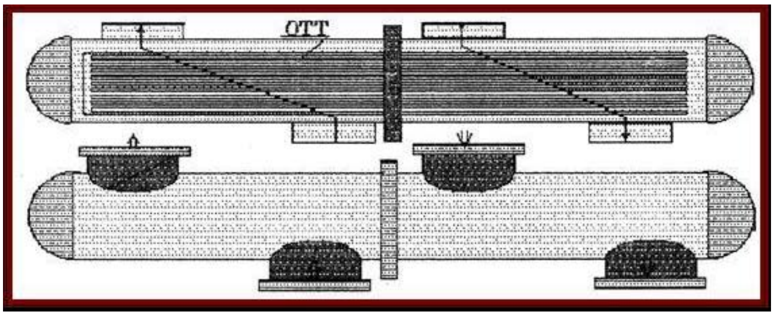

Fig. 9. The industrial type of oscillating heat exchanger.

The industrial type of oscillating heat exchanger of that of schematically represented on Fig. 9 is developed on the basis of the results of testing. It is assumed the heat exchanger 2-meter length project capacity is 60 kW. Design development made it possible to determine the advantages and insufficiencies in such type of heat exchanger:

- effective area is not less than in most effective classical heat exchangers;
- minimum weight and overall sizes;
- maximum operating pressure for flows > of 150 atm;
- a maximum pressure difference between the flows > of 150 atm;
- high reliability because of minimum quantity of the welds: in thousands of times it is less than in lamellar;
- the dual guarantee of the absence of overflow between the media;
- operation convenience: movable guards make it possible to conduct cleaning heat exchange surfaces and repair;
- minimum cost because of the technical ease of manufacture and small material consumption;
- the reduced operational expenditures in connection with the lowered hydraulic resistance.

The marketing development made it possible to determine the next fields of OHP application:

- in heating systems and hot water supply;
- for heat-utilization of water discharges;
- in heat pumps and cooling setups as the vaporizer or condenser;
- as the oil cooler for transformers, the forced lubrication systems and hydraulics;
- as the oil heater.

The complex of qualitative and quantitative studies of operation of oscillating heat pipes and heat transfer devices on their base show the advantages and deficiencies of such devices.

The fields of application for devices was determined and the most perspective are the next:

- Cooling electronics;
- Solar heating of medium;
- Utilization of heat from different medium;

Partly the work was carried out with supporting of Fundamental Research Fund of National Academy of Sciences of Belarus (№ T03-042M).
Manufacture and testing the solar collectors and heat exchangers was made with involvement A.Korseko.

References

1. Vasiliev, L.L., Konev, S.V., Heat pipe, *Scripta Technica*, Washington, 1974.
2. Akachi, H., Looped Capillary Heat pipe, *Japanese Patent*, № Hei6-97147, 1994.
3. Koneva, N.S. Zakharenkov, M.B, Theoretical model, the results of optimization of type and construction of solar collector in connection with conditions RB, *Proc. of International conf. «Recourse saving ecotechnologies: renewal and saving the energy, the material and the raw material»*, Grodno, October 2000 (in Russian).
4. Aliakhnovich V., Konev S.V., The software development for optimization of studies of vaporization process in capillary channels, *Annual book «Heat and mass transfer»*, Minsk, Luikov H&MTI of NANB, 2003 (in Russian).