MINIATURE LOOP HEAT PIPES WITH NONINVERTED MENISCUS

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Abstract

Evaporators with inverted meniscus traditionally use in miniature loop heat pipes (MLHP). They require using capillary structure with relatively high thermal resistance to avoid vaporization in compensation camber. Developed MLHP with noninverted meniscus allows using capillary structure with high thermal conductivity. It results to the simplification of capillary structure design and temperature resistance decreasing. Experimental investigations of manufactured MLHP with noninverted meniscus shown that thermal resistance of evaporator with noninverted meniscus is significantly less than own thermal resistance of evaporators with inverted meniscus.

KEYWORDS

Loop heat pipe, inverted meniscus, noninverted meniscus, capillary structure, heat transfer

INTRODUCTION

Rapid technique development creates new requirements to provide heat regimes, which can't be satisfied by heat pipes of conventional design. One of mentioned requirements is the necessity to provide a heat pipe operation in the mass forces field in the case of quite great heat transfer distance. In mentioned conditions the most complex problem to be solved is heat transfer in antigravitational conditions when working fluid returning into evaporation zone is in direct opposition to the gravitation force. The same situation may be also appears due to inertial overloads in moving objects. Physical aspect of operation limits in these cases is condition of the quite great hydraulic resistance and relative low capillary pressure. Quite great distance of heat transfer at any orientation in the gravitational field is provided by loop heat pipe with inverted meniscus (Fig. 1). It is means that heat and liquid flux are directed opposite to each other in the evaporation zone [1].

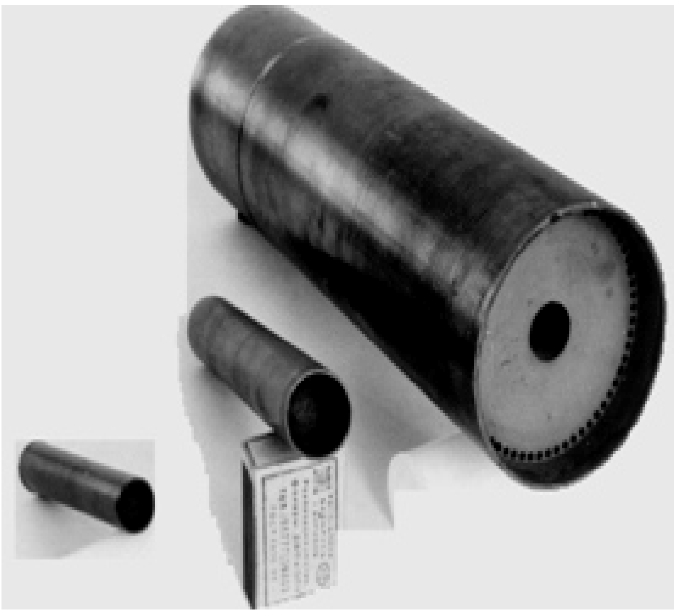


Fig. 1. Evaporators of loop heat pipes with inverted meniscus

Because of a small distance between evaporation zone and compensation camber capillary structure should be used of metal powder with quite small thermal conductivity (such as nickel, titan).It leads to the increasing of evaporator thermal resistance.

In the work [2] a MLHP is described with cylindrical evaporator of 5–6 mm diameter and 0.2–0.25 m effective length which were developed for electronics cooling and have thermal transfer capacity of 80 W at any orientation in gravity. Own thermal resistance of MLHP is 0.3 – 0.5 K/W.

In the work [3] the possibility to use such MLHP for cooling notebook PC without cooler is shown. However it is admitted that the cost of mentioned systems is quite large and there is a problem to develop cheaper but not less effective systems of electronics cooling on the base of miniature LHPs.

In the work [4] MLHPs with titanium and nickel capillary structure were investigated. The best evaporator thermal resistance was 0.15 K/W at horizontal orientation of MLHP. But it should be accented that in [4] capillary structure consisted from 4 parts: biporous nickel layer, monoporous nickel layer, titanium layer and secondary wick. Apparently described construction is much expensive than for example uniform copper structure. Moreover the price of MLHP maintains great due to quite complicated geometry of capillary structure.

Therefore it is reasonably as decrease thermal resistance of evaporator as simplify the capillary structure. The concept of miniature loop heat pipe with noninverted meniscus seems us appropriate for this purpose.

MINIATURE LOOP HEAT PIPES WITH NONINVERTED MENISCUS CONCEPT

As a rule all tested in presence cooling systems based on MLHP use evaporators (diameter about 6 mm) of the same design that LHP of lager size (with inverted meniscus). It means that thermal resistance of such cooling systems maintains quite large. However, relatively small sizes of PC components allow avoid the inverted meniscus principle, arrangementing of longitudinal motion and evaporation of liquid in LHP evaporator by the scheme of conventional HP (with noninverted meniscus) [5, 6]. By this way it is possible to use materials with high heat conductivity such as copper for evaporator frame and capillary structure. It leads to essential decreasing of evaporator thermal resistance.

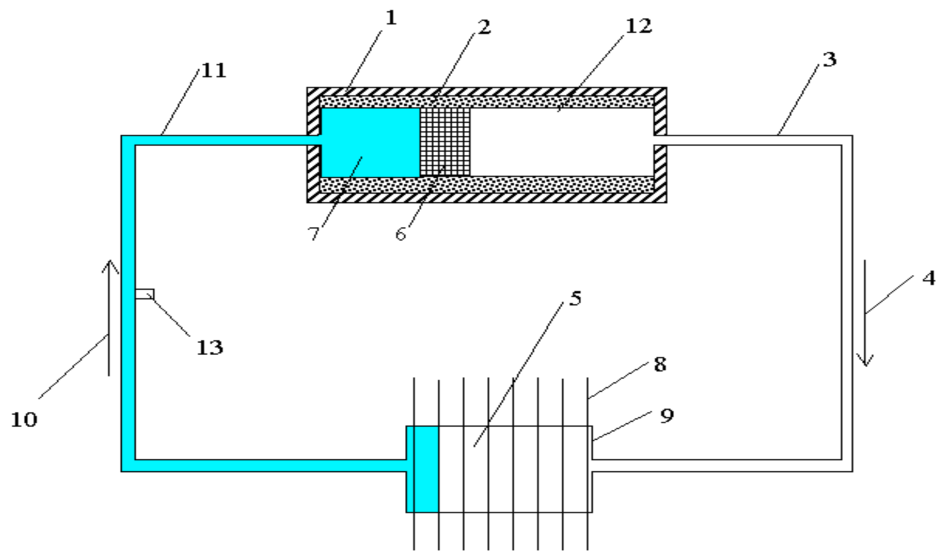
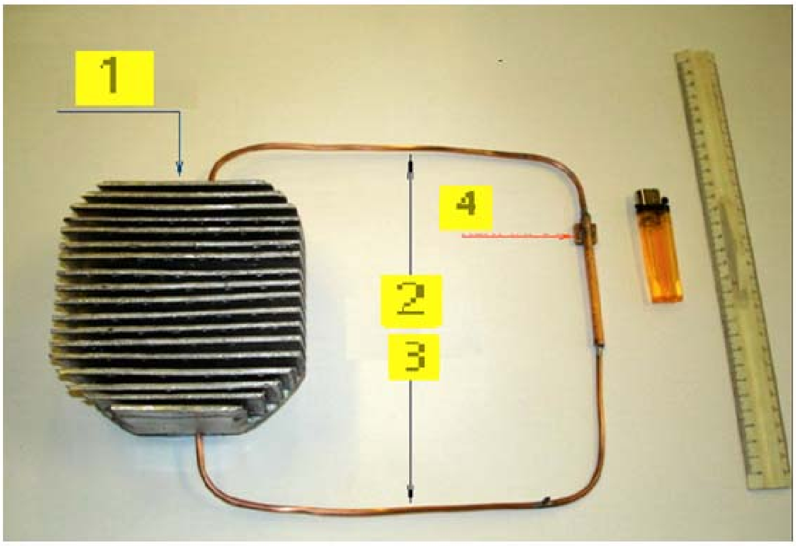


Fig. 2. MLHP with noninverted meniscus: 1 – frame, 2 – capillary structure near the frame, 3- vapor line, 4 – vapor flux direction, 5 – condensation zone, 6 –plug, 7 – compensation chamber, 8 – sink, 9 – condenser, 10 – liquid flux direction, 11 – liquid line, 12 – evaporation zone, 13 – connecting pipe

The LHP evaporator case may be both cylindrical and flat. The simplest flat evaporator design performing noninverted meniscus principle is shown in Fig. 2. Capillary structure may be divided on two parts. The thicker part totally overlays space inside the case dividing compensation chamber and vapor channel and serving as a hydraulic and heat plug. Thin part of capillary structure is displaced at the case wall and serves for liquid distribution overall the heat receiving surface and for effective heat exchange due to liquid evaporation from porous space. Photo of the MLHP with noninverted meniscus is given in Fig. 3.

Due to quite great distance between evaporation zone and compensation chamber it is possible to make capillary structure form copper.



1- SINK, 2 - VAPOR LINE, LIQUID LINE, 4 - HEATED SURFACE

Fig. 3. MLHP with noninverted meniscus

NEW PRINCIPLE AND VOLUME CORRELATION FOR MLHP START UP

There is well known volume correlation for successful loop heat pipe start up [7]: $V_{c.z} + V_{v.l} \le V_{c.ch}$. It means that any time there is a liquid bulk near the capillary structure and it provide the start up. But if MLHP must transfer about a hundred Watt to the distance about several dozens centimeters the volume of compensation chamber should be about several dozens milliliters. It greatly confines the possibilities of evaporator miniaturization. It requires finding new principle of MLHP start up for much more acceptable volume conditions using.

New principle provides the condensation of vapor between liquid bulks in liquid line and capillary structure. It requires following conditions:

- volume of condensation zone should be less than the porous volume in the evaporation zone;
- volume of condensation zone should be less than the volume of compensation chamber.

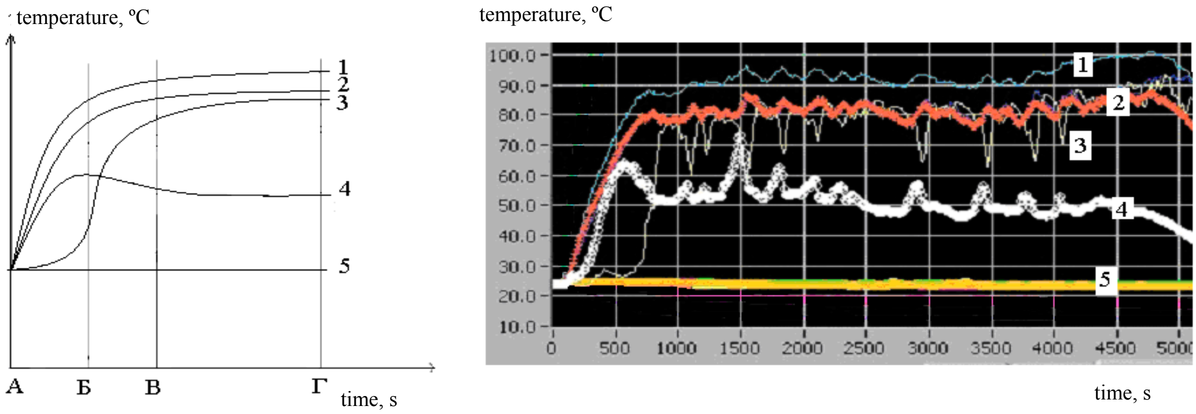
Lets accept the first condition. If compensation chamber totally filled by vapor, then condensation zone should be filled by liquid before the capillary structure in evaporation zone dryout. Consequently due to further evaporation from capillary structure the pressure in vapor line will be greater than in compensation camber. It pushes liquid bulk to the compensation chamber and partly dryout capillary structure. It results to the MLHP start up.

Lets accept the second condition. If compensation chamber totally filled by vapor, then condensation zone should be totally filled by liquid. Then just as the first one because the pressure in vapor line become more than in the compensation chamber liquid bulk will be pushed to the compensation chamber and partly dryout capillary structure. It results to the MLHP start up.

Having analyzed both conditions one may formulate general volume correlation:

$$V_{c.z} \le V_{c.s.e.z} \cdot \Pi + V_{c.ch} \,. \quad (1)$$

Then the way of MLHP start up is following (Fig. 4 a). If compensation chamber filled by vapor initially then condenser temperature increase negligible because liquid is filling condenser and vapor cannot penetrate there (line AB). When condenser become totally filled by water , temperature and pressure difference between evaporation zone and compensation chamber increases. It pushes liquid bulk to the compensation chamber. At the same time condenser temperature increases because the vapor gets access to the condensation zone. Compensation chamber is cooled due to the flux of cold liquid from the liquid line (line BC). When compensation chamber totally filled by liquid MLHP performs stationary (line CD).



a) b)

Fig. 4. Theoretical (a) and experimental (b) temperature dependences versus time during MLHP start up: 1 – heater; 2 – evaporation zone; 3 – condensation zone; 4 – compensation chamber; 5 – ambient

Fig. 4 (b) shows experimental results of MLNP start up temperature measurements made by Dr. Donatas Mishkinis in Canadian Space Agency. Fig. 4 shows than experimental and theoretical data correlate each other.

EXPERIMENTAL INVESTIGATION

Experimental dependence of temperature difference between evaporator and vapor line (thermal difference over the evaporator) versus heat load of MLHP test in horizontal orientation is shown in Fig. 5. Rapid increasing of temperature difference at high heat load is explained by capillary structure dryout.

The thermal resistance of evaporator with noninverted meniscus is about 0.05 K/W. It is significantly less than thermal resistance of evaporators with inverted meniscus [2–4]. Additionally it should be noted that described MLHP with noninverted meniscus had extremely small heat input surface (order of 1 cm^2) in comparison with MLHP with inverted meniscus. For instance in [4] MLHP with inverted meniscus had heat input surface equal 10 cm^2 and thermal resistance about 0.15 K/W. Consequently MLHP with noninverted meniscus is able to remove heat fluxes with much greater density than MLHP with inverted meniscus.

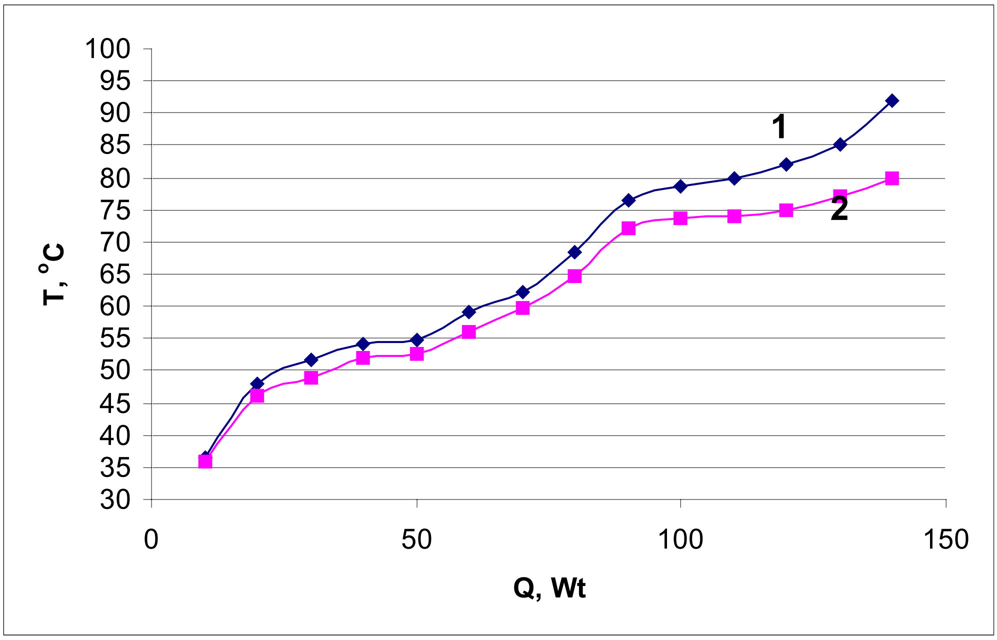


Fig. 5. Results of MLHP test: 1 – evaporator temperature, 2 – vapor line temperature

CONCLUSION

Concept of miniature heat pipes with noninverted meniscus is described. New volume correlation for MLHP start up is formulated. Experimental test of MLHP with noninverted meniscus shown that own thermal resistance of evaporator with noninverted meniscus is significantly less than own thermal resistance of evaporators with inverted meniscus. Additionally MLHP with noninverted meniscus is able to remove heat fluxes with much greater density than MLHP with inverted meniscus.

NOMENCLATURE

V volume

Greek

Π porosity

Subscripts

c.ch compensation chamber

c.s.e.z capillary structure in evaporation zone

c.z condensation zone

v.l vapor line

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