DEVELOPMENT AND INVESTIGATION OF A COOLER FOR ELECTRONICS ON THE BASIS OF TWO-PHASE LOOP THERMOSYPHONS

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Abstract

The objective of this work was the development of a device for cooling electronic elements with a heat power up to 30 W by its rejection and dissipation in the ambient by free air convection. The device's specification assigned the temperature range of the ambient conditions changes by the interval from −40 to +105 °C and the available space of 30(W)×120(H)×200(L) mm. As a result a hybrid scheme on the basis of a loop thermosyphon was proposed, where the evaporator embodied the capillary structure. In such a scheme the return working fluid flow was ensured by the combined action of the gravity and capillary forces. Several prototypes with different loop and evaporator designs were tested in laboratory conditions. Water and heptane were used as working fluids. The experiments showed that the role of the capillary structure locally placed in the evaporator can be efficiently implemented by both high-porous cellular materials and capillary grooves made on the evaporating surface. It is shown as well that heptane can be effectively used as a working fluid which is appropriate for the temperature range requirements. At the same time the device has good mass-and-size characteristics and total thermal resistance under a nominal heat load of about 1.7 °C/W.

KEYWORDS

loop thermosyphon, evaporator, capillary structure, thermal resistance

1. INTRODUCTION

The simplicity of the two-phase thermosyphons (TS) design is as a whole the main factor which has attracted to them great attention for many years. As the return of liquid from the condenser in the evaporator is realized under the gravity forces, then these devices application is limited by the terrestrial conditions. Nevertheless TCs allow quite a technological solution for a wide range of thermal problems and, particularly, electronics cooling problems [1]. Because of the high dense electronics packaging in the limited space, the cooling device compact size and its convenient placement become very important. In view of this, the loop thermosyphon (LTS) design where the evaporator is attached to the condenser by a pair of individual channels for liquid and vapor flows has several advantages over the tubular TS. Firstly, the entrainment thermal limit typical of the tubular TS is eliminated. Secondly, the connecting channels can have a relatively small diameter, which allows its easy configuration. And, finally, the evaporator and the condenser can have different geometry and sizes corresponding to the concrete conditions of the external heat exchange.

The limitations of the LTS thermal performance first of all are connected with two basic limits. The first one is the so-called pressure losses limit, which appears when the total hydraulic losses in the loop become equal to the pressure of the highest possible hydrostatic liquid column. The second one is related to the boiling limit, which for the smooth internal surface of the evaporator and under the flooded condition is close to the values of the pool boiling limit. [1].

The requirements of modern electronics with the necessity of cooling elements with heat rejection densities up to 100 W/cm^2 and more stimulated the appearance of a large member of research works concerning the heat transfer intensification in evaporators by enhancing the internal surface. The main efforts in this direction consist in the creation of a thin grooved system, porous coatings of sintered powders or fibres and porous inserts [2–7].

In this connection the effect of an enhanced surface on heat transfer during boiling on it is studied in a liquid flooded horizontal position. For these conditions the increase of critical heat fluxes in

comparison with a smooth surface may range from one and a half [1] to six [2, 5] times. The typical size of structural grooves is usually equal to 0.3–0.55 mm. The range of sintered structures optimal thicknesses is from 0.1 to 1.5 mm at a porosity of 49–80 % and at pores sizes of about 50-200 μm. The

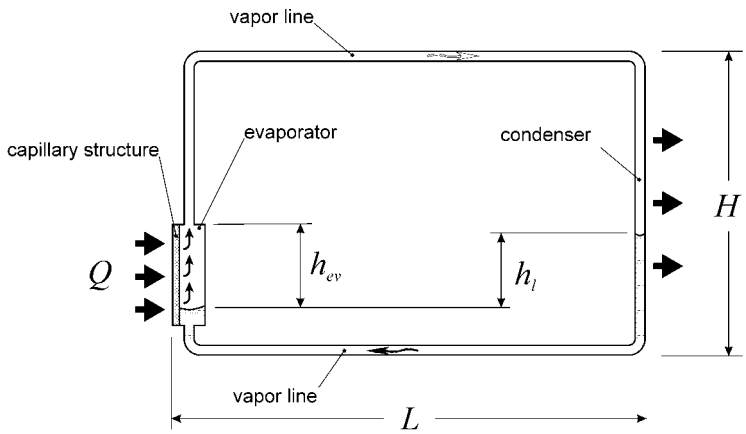

Fig. 1. Principal scheme of hybrid LTS

conditions of the capillary feeding of porous coating were realized in the work [4] where was obtained a 2-3 order increase of the heat-transfer coefficient in the range of low and moderate heat fluxes 0.1-10 W/cm^2. The data were obtained on a sintered copper coating 0.3 mm thick with a porosity 50–55 % and a pore size of 24.5 μm. The working fluid was R290 (propane).

The row of working fluids, examined in the LTS for electronics cooling is limited by the following line: water, ethanol, methanol, PF5060, FC-72. Water is often excluded from this line because of the abnormal density during freezing. Freon R134a was successfully used for a thermoelectric refrigerator with a working temperature range from –5 to +5 °C [8].

The objective of this work was the development and tests of a heat transfer device which would allow heat rejection into the ambient from the electronics elements with a maximal admissible temperature of 150°C and in a wide temperature range of the ambient medium from – 40 to +105 °C. The device should conform to the specification by the dimensions and should be easily made.

2. DESIGN PROCESS

The design specification for the heat transfer device is presented in Table 1.

Table 1. Design specification

Maximal heat load	30 W
Maximal admissible temperature	150 °C
Range of the ambient temperature	-40+105 °C
Sizes of the contact area	30×30 mm
Available volume for the cooling device	30(W) ×120(H) ×200(L) mm
Inclination	0±20°
Means of external radiator cooling	free air convection
Mass of the device	minimum

The LTS scheme was taken as the basic one. There the heated evaporator surface is placed vertically and its bottom is almost at the same level as the condenser bottom (Fig. 1.). Such a composition was enforced by the limited height H =120 mm. It was supposed that the effective work of such an LTS can be realized at a partial flooding of the evaporator by organizing on its hot side a

capillary structure to realize the liquid feeding and evaporating cooling. Besides, it would allow decreasing the required height h_l of the driving liquid column.

Then the working fluid circulation conditions can be described by the system of two equations:

$$\Delta P_g(h_l) = \Delta P_v + \Delta P_l \quad (1)$$

$$\Delta P_c \geq \Delta P_l^{CS} + \Delta P_g(h_{ev}) \quad (2)$$

Equation (1) describes the condition of equality of the hydrostatic pressure of the liquid column with height h_l to the sum of hydraulic losses in the vapor and liquid lines (ΔP_v and ΔP_l, respectively). Equation (2) is the capillary limitations when the maximal capillary head ΔP_c should exceed the pressure losses at the filtration of liquid ΔP_l^{CS} through the wick and its lifting to height h_{ev}, $\Delta P_g(h_{ev})$.

Based on these equations, the selection of the LTS design parameters and of the working fluid was carried out. Besides, the working fluid selection along with the condition of nonfreezing was limited by the value of the excessive pressure of 3-4 bars. Only two working fluids meet this requirement: toluene and heptane with saturation pressures of 2.18 and 3.0 bars at a temperature 140 °C respectively. An estimated calculation for them was made by the equation (1) to find the value of the liquid column appearing at a 30 W heat load in the LTS loop with an inner diameter of lines of 3 mm. The calculation results are presented in Figure 2 as a function of the temperature. It is clear that at the same working temperature the height of the column for heptane is lower than for toluene up to 100 °C.

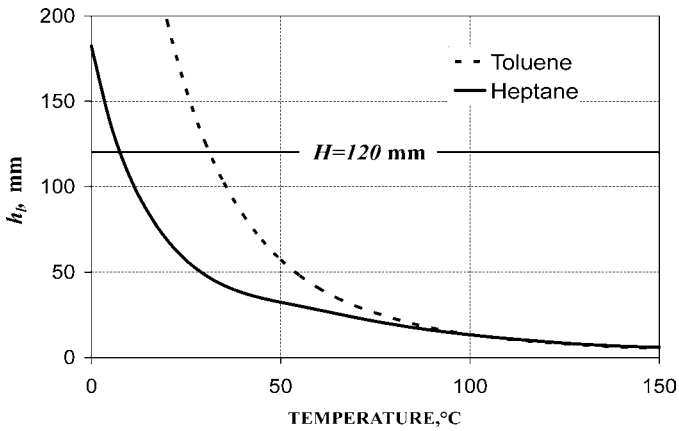

Fig. 2. Temperature dependence of the liquid column height in LTS for toluene and heptane.

It is important for the LTS scheme under consideration because the liquid column blocks part of the condenser surface. Besides one can see that due to the height limitation in the maximal possible column of the LTS (H = 120 mm), the stationary circulation in the loop is possible not at all temperatures. For heptane it starts at lower temperatures of about 10 °C than for toluene of about +30 °C. The arguments listed acted as a reason to choose heptane as a working fluid.

3. LTS EXPERIMENTAL MODELS

Three prototypes with different types of condensers and evaporators were made and tested. Their designs are shown in Figure 3 together with the radiators they were tested with.

Model #1 had a cylindrical evaporator supplied with a copper saddle. A porous insert of a copper high-porous cellular material (HPCM) was placed in the evaporator. In models #2 and #3 evaporators had the same disk shape but different capillary structures (CS). In model #2 a CS of copper HPCM 2.4 mm thick was pressed mechanically to the inner heat-receiving surface of the evaporator. In model #3 the CS was made as a row of vertical grooves 0.1 mm wide and 0.25 mm deep. In all models the

condensers were of tubular type, which during tests were mechanically pressed to the base of radiators. Noteworthy is a peculiarity of the condenser in model #2, which for greater compactness was made as a loop with two lines. One of them was ascending, i.e. the flow was directed against the gravity forces vector, the other line was descending.

All the models were made of copper. In models #1 and #2 water was used as a working fluid. Model #3 was filled with heptane. The mass of a filled model #2 was about 64 g, of models #2 and #3 - 54±1g.

A flat electric heater was used as a heat load simulator, which through the thermal paste was pressed to the heat-receiving side of the evaporator. The heat load range varied from 10 to 40 W. The radiator cooling was effected by free air convection at an indoor temperature of 22±2 °C. The temperature was measured by T-type thermocouples placed on the heater contact surface, on the vapor and liquid lines and on the radiator base. During tests the record of the temperature field in time was made, simultaneously the heat load was changed stepwise following the steady-state conditions. Tests were conducted at the devices horizontal orientation and at slopes of ±20°.

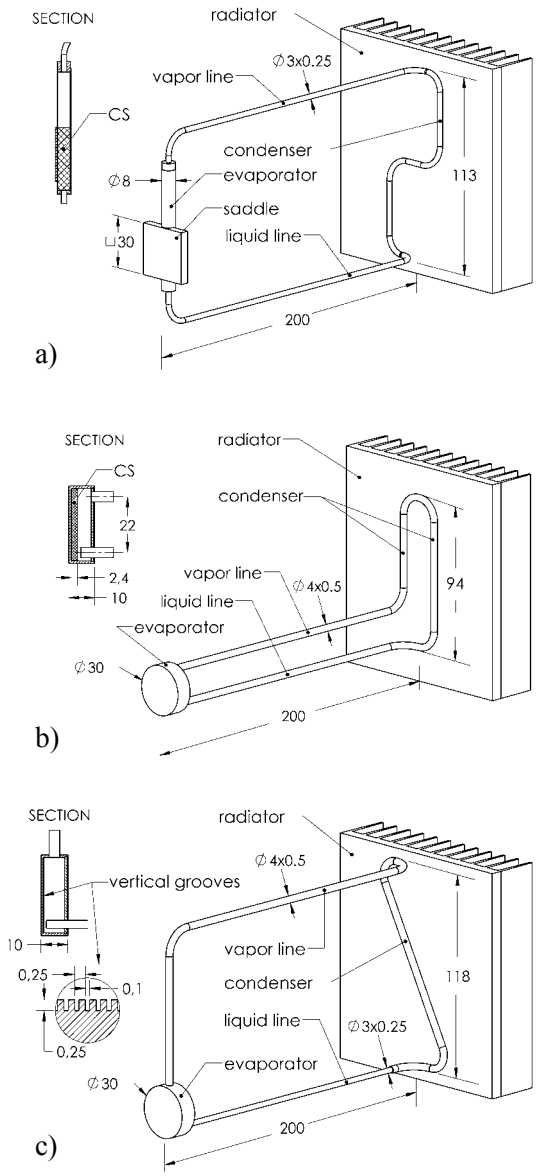

Fig.3. Experimental LTS designs:
a) model #1, b) model #2, c) model #3.

4. TESTS RESULTS, DISCUSSION

Typical temperature-time dependences of LTS operating regimes obtained during experiments are shown in Figure 4. It is clearly seen from Fig. 4a that a start-up of model #1 was accompanied with overheating of the liquid in the evaporator followed by sudden boiling and heating of the loop. Slight fluctuations of the liquid and vapor lines temperatures are seen as well, they decreased with increasing heat load. Hence it can be supposed that in the initial state the internal porous insert in the evaporator was fully saturated with the liquid. After boiling, and as liquid was removed from the large pores of the HPCM during the increase of the heat load, the evaporation regime started and the circulation flow stabilized.

The work of model #2 was accompanied by significant fluctuations of all the temperatures (Fig. 4b) and by a relatively higher temperature level under lower heat loads than in model #1. Such a behavior can be explained mainly by the geometry peculiarity of the loop-shaped condenser.

The formation of a continuous liquid plug in its lines led to the limitation of the maximal height of the driving liquid column to the value of 22 mm (the distance between the vapor and liquid lines on the transport section (see Fig. 3b). On the other hand, liquid was ejected from the evaporator in the loop pipes on explosive boiling up. At low temperatures this liquid column pressure was insufficient for the overcoming of the pressure losses in the loop. During the condenser blocking by the liquid, the temperatures grew to values when the mentioned height became sufficient to provide the liquid access to the evaporator. Besides, the inflow of the sub-cooled liquid in the evaporator stimulated the

initiation of pressure and temperature pulsations. It can be seen as well that the amplitude of temperature oscillations decreased along with the heat load growth but didn't disappear at all even on the achievement of its maximal value.

It is seen from model #3 operating characteristics (Fig. 4c) that its start-up was smooth without temperature pulsations and with progressive warming-up of the loop. It allows concluding about the prevalence of the evaporative mechanism of the vaporization in the CS made as capillary grooves. The crisis was not observed up to a heat load of 40W, which corresponded to a heat flux of 5.66 W/cm^2.

The comparison of total thermal resistances is shown in Figure 5. This thermal resistance was determined as the relation of the temperature difference between the heater contact surface and the ambient to the supplied power. It means that it included all the contact resistances as well: LTS-heater and LTS-radiator.

It is seen that the significant difference in the values of the total thermal resistance was observed only under low heat loads of 10–20 W, which can be explained by the device different operating regimes described above. Under a nominal heat load of 30 W models #1 and #3 had the lowest resistance of about 1.66±0.01°C/W.

The tests of the inclinations influence on the LTS operation were executed with models #1 and #3 at the nominal value of heat load 30 W (Fig. 6). It is seen that quantitative and qualitative

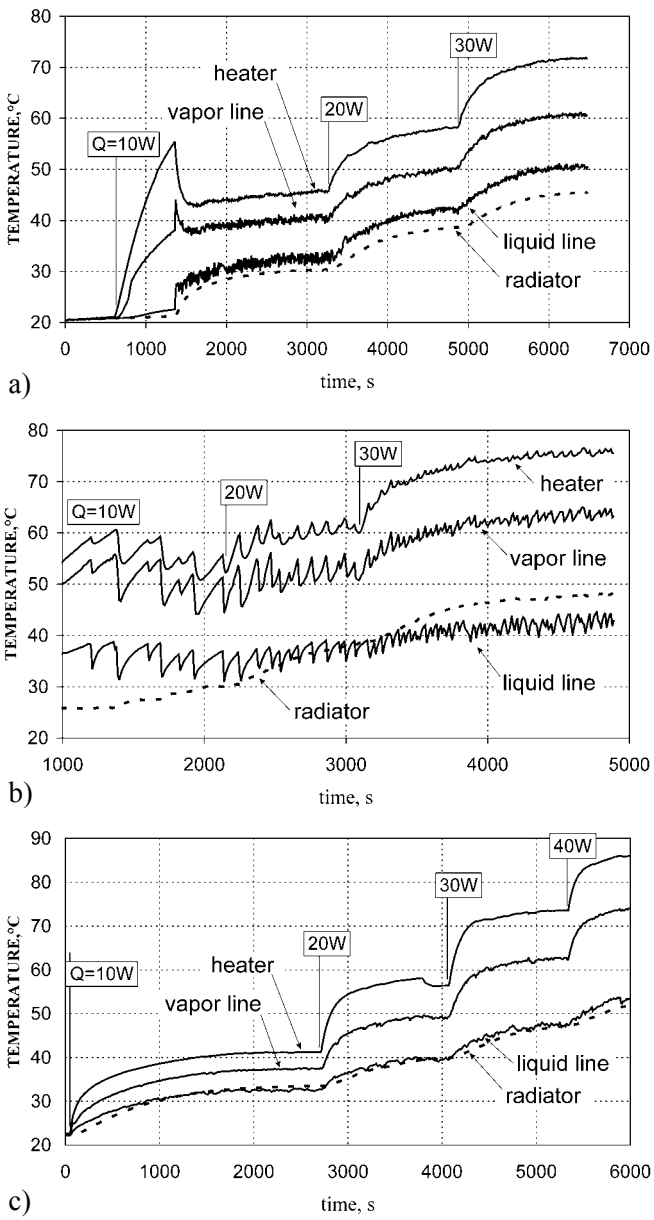

Fig. 4. Temperature-time dependences of the operating regimes at the orientation φ=0°: a) model #1, b) model #2, c) model #3.

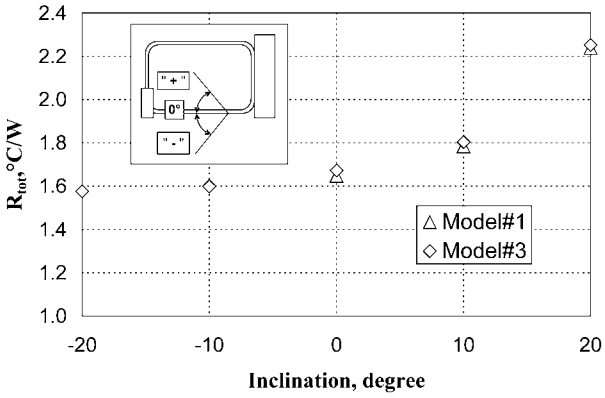

Fig. 6. Total thermal resistance vs LTS slopes. Heat load 30 W is constant

characteristics were very close. The main influence of the slopes in the interval of ±20° on the characteristics can be connected with the change of the flooding degree of the condenser. At negative inclinations the condenser was rid of liquid while at positive ones - it was filled with liquid. Besides, at positive inclinations the degree of the evaporator filling with the liquid decreased. Hence it is clear why the device was more sensitive to positive inclinations than to negative ones. It is obvious that greater

positive inclinations are fraught with the violation of conditions of the working fluid circulation and as a result with full drying of the evaporator.

5. CONCLUSION

1. In soling the task of creating a compact and simple heat transfer device a design on the base of a two-phase LTS, where the evaporator was supplied with a capillary structure, was proposed and tested. Tests of three experimental models have shown that at heat fluxes up to 5–6 W/cm^2, both HPCMs and constructive capillary grooves can be used as CS. It has been determined as well that the condenser in the form of a loop with an ascending line leads to the pulsation regime in the device operation.
2. The selection of heptane for a wide operating temperature range (-40°C…+140 °C) of the device is justified. Heptane as a working fluid was approved in LTS at vapor working temperatures from 37 to 74 °C. The total thermal resistance of the device at free-convectional air cooling at a heat load of 30W didn't exceed 1.7 °C/W.
3. At the change of the inclinations to the horizon in the interval of ±20° the device remained workable. The corresponding range of the change in the total thermal resistance amounted to 1.58…2.25 °C/W.
4. For realization of the device's practical application it seems actual to carry out an investigation of its working regimes in the whole temperature range from -40 °C to +105 °C prescribed by the specification. Of special interest are start-up regimes at low temperatures when a pronounced pulsation regime of operation is expected.

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