MINIATURE PULSATED LOOP THERMOSYPHON FOR DESKTOP COMPUTER COOLING: FEASIBILITY STUDY AND FIRST EXPERIMENTAL TESTS

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Abstract

The quick growth in the use of electronic packaging has created critical values on the maximum heat flux dissipation, above all in comparison with the previous devices cooled by forced air. Heat pipes, LHPs and CPLs are really the most efficient cooling devices in this case, but their high cost can limit their use in commercial devices. Recent innovations, in loop thermosyphons design, have had a relevant impact on the electronic equipments thermal control for high density desktop computers, but one of the most critical topic of this device is the gravity dependence on its heat transfer properties.

For this reason some particular devices, named Pulsated Two-Phase Thermosyphons, operating against gravity with natural circulation, were been developed. Their running is low frequency pulsated and it has been previously investigated by the authors in collaboration with the Moscow Power Institute.

This work analyses the feasibility design of a cooling device with PTPT for desktop computers. By use of a calculus code created by the authors in cooperation with MPI and validated by means of data collected in previous experimental tests, a mini experimental apparatus based on a PTPT heat transfer regime has been realized. First experimental results are reported and discussed.

KEYWORDS

Desktop computer processor cooling, miniature Pulsated Two Phase Thermosyphon, passive heat transfer.

INTRODUCTION

The quick evolution of electronic equipments and its packaging has created critical values on heat flux dissipation in commercial devices as for example in the desktop computer processor coolers. The last generation of personal computer processors needs to dissipate thermal power of 70 W about, that is a heat flux of 5-10 W/cm^2, and the chip temperature under 100 °C with an high temperature uniformity over its transfer surface.

A lot of cooling equipments based on two phase heat transfer devices have been developed in a recent past [1], [2]. For example Xie et al. [3] proposed a heat pipe to connect the Pentium® processors surface with a cooling plate surface located on the back of the video in a notebook. Other solutions with cylindrical heat pipes have been recently studied in [4].

Miniature flat heat pipe applications have been studied by Krustalev e Faghri [5], Vasiliev L. L. e al. [6] and Ponappan [7]. In particular the last one shows the performance of a 12.7 x 6.35 x 107.9 mm heat pipe able to dissipated a heat flux of 142 W/cm^2 with a temperature difference evaporator – condenser of 22 K.

Recently micro heat pipes have been studied and applied for the chip cooling by Babin and Peterson [8], Wu [9] and Shen [10]. The typical diameter of a micro heat pipe is 10 - 100 μm but the maximum heat transfer rate is 0.3 W. A review of this innovative technique is reported in [11], while some critical aspects are well described in [12].

Other devices as LHPs and CPLs, developed for low gravity applications, are proposed at the moment for terrestrial application too, because they have good heat transfer performance anyway located respect to the gravity. Some interesting application of LHPs are reported in [13]- [14] while CPLs applications in [15] e [16].

In 2001 Chen and Lin [17] shown a CPL to cool a Pentium Processor using FC72 as working fluid instead of water. This solution allows an approach with direct cooling technique which presents lower thermal resistances. The maximum heat transfer rate is 30 W (2 W/cm^2) with the condenser at the same level of the evaporator. However, in this case, the temperature of the chip grows up till a value of 115 °C.

The excellent thermal performance reached with this kind of heat transfer devices, even with very small size, make them adequate for the cooling of notebook processor and other microelectronics applications. On the other side their high costs in comparison with forced air heat sinks limit at the moment their use in commercial applications. For this reason, it seems convenient to develop two phase heat transfer devices, without any capillary structure to transport heat and mass as the pulsating heat pipes and two phase loop thermosyphons.

The pulsating heat pipes is a recent technology that uses working fluid pulsations to transport heat and mass in a loop[18]. It is possible to have a heat transport also with the condenser at the same level of the evaporator or with tilt angles very low, but the maximum heat fluxes transferred in this case are 1 - 5 W. Applications for electronic equipment cooling are shown in [18] [19].

Recent innovations in loop thermosyphons design have had a relevant impact on the electronics thermal solution for high density desktop computers, because they can represent a low cost solution really competitive with the fan coolers. Garner and Patel [20] outlined in detail a big number of commercially and technically electronic and microelectronic solutions using loop thermosyphons, while Polasek and Rossi presented some technical solutions with miniature loop thermosyphons [21]. The loop thermosyphon presented by Krustalev in [22], for electronic equipment cooling is certainly more interesting. It consists of an evaporator and a condenser with the same external size (65 x 90 mm). The condenser is located 60 cm higher than the evaporator. The internal diameters of connection pipes are 6 mm for liquid line and 12.5 mm for vapour line, while the working fluid is methanol. The maximum heat flux removed is 960 W (about 16 W/cm^2), the temperature of liquid is about 50 °C, while the temperature of the condenser is 22 °C lower. A similar loop thermosyphon has been realised by Khodabandeh and Palm and used to study the influence of the pressure on the heat transfer boiling coefficient [23].

One of the most critical topics of electronic mini applications cooled by thermosyphons it is that they are not capable to transfer heat and mass downwards. Some particular devices, named Pulsated Two-Phase Thermosyphon, operating against gravity with natural circulation, were developed in the past above all for solar heating and cooling. Their running is a low frequency pulsation regime and it has been previously investigated theoretically and experimentally by the authors in collaboration with the Moscow Power Institute [24] - [29].

Previous works have experimentally shown as a PTPT device can well suit to electronic equipment cooling [24], but all the tests have been made with a big size apparatus. This work analyses the feasibility study and the realisation of a cooling device for desktop computer based on a PTPT heat transfer model. By use of a calculus code created by the authors in cooperation with MPI and validated by means of data collected in previous experimental tests [29], a mini experimental apparatus based on a PTPT heat transfer regime has been realised. First experimental results are reported and discussed

PULSATED TWO PHASE THERMOSYPHON (PTPT)

A generic PTPT consists of an evaporator, a condenser anyway located respect to the gravity and an accumulator, separated from the evaporator. The evaporator is connected with the condenser through a vapour line and with the accumulator through a liquid return line. The line connecting the condenser with the accumulator is named liquid line. Two check valves drive the flow in a fixed direction. A diagram of a generic PTPT is shown in Fig 1. The main operating principles of a PTPT are well described in [24] [25] [29].

At the starting time, the evaporator is full of working liquid, while the other components are empty. As a heat flux is supplied to the evaporator wall, liquid vaporizes and evaporator pressure increases according to an isovolumic transformation. The vapour is pushed through the vapour line to the condenser, because the return line is closed by a check valve. Till the evaporator pressure is lower than the pressure reported in eq. (1), the condensed liquid is motionless.

$$p_s(T_1) \leq p_s(T_5) + \rho'(T_3) \cdot g \cdot H_{tot} - \rho''(T_1) \cdot g \cdot H_{agt} \qquad (1)$$

As soon as the evaporator pressure increases above the value expressed by the inequality (1), the condensed liquid moves into the accumulator, the evaporator is gradually emptying and the accumulator is filling. To make possible the return of the liquid collected in the accumulator, the pressure difference between evaporator and accumulator must invert its sign.

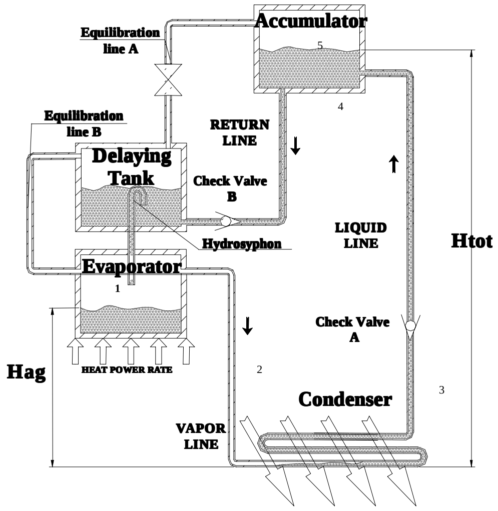

Figure 1 – Functioning scheme of a PTPT.

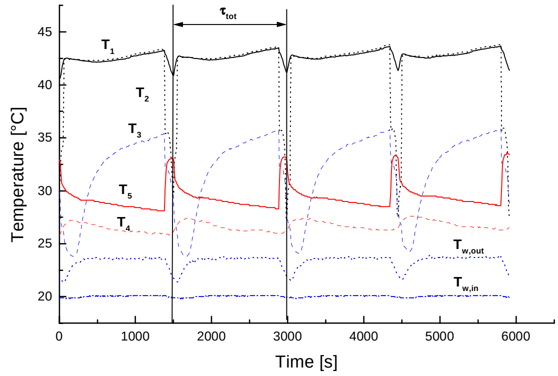

Figure 2 - Temperatures for 4 heat transport cycles in a PTPT.

There are three different ways to make possible the liquid return from the accumulator to the evaporator [24], but the most used are two, named in this work A and B devices.

In the A-devices, the return operation starts as the evaporator is empty, so that the pressure inside decreases till to the saturation pressure at environmental temperature [26]-[28], [30].

The evaporator pressure reaches a value lower than the pressure inside the accumulator minus the pressure drop in the return line, so that the cold liquid collected in the accumulator moves towards the evaporator, closing the cycle. The A-devices have however a well described critical problem [27], [30]. As the first cold liquid drops coming from the accumulator reach the hot surface of the evaporator, they vaporize immediately and the inside pressure grows so quickly that the accumulated liquid mass can not return in the evaporator. For this reason a delaying tank with an hydrosyphon at the same pressure of evaporator (Fig.1) is inserted. This solution is surely the most studied and experimentally tested [26]-[28].

In order to close the cycle for the B-devices, the evaporator is connected with the accumulator by means of an equilibration line (equilibration line A, Fig. 1). The accumulator located over the evaporator drives the liquid return assisted by gravity as the equilibration line is opened. The control of the opening and closing valve in the equilibration line A, can be actuated electrically or mechanically. A B-device has been experimentally investigated [24] and its typical oscillating temperature inside the loop has shown in Fig. 2 , when a periodic stabilised regime is reached.

A mathematical model created to simulate thermal behaviour of a PTPT has been developed in collaboration with the Moscow Power Institute [28]-[29]. This code, named PTPT simulator, can predict the trend of the working fluids main parameters versus time, from the start up till a periodic stabilized regime.

The system of nonlinear differential equations is solved using the integration Euler method. A more complex method is not requested being a low frequency physical phenomenon. The mathematical model is able to predict the experimental data with a good qualitative accordance with errors lower than 15% on the heat transport time and lower than 5% on the evaporator temperature [28]-[29].

EXPERIMENTAL SET UP DESIGN

The aim of this research activity is to analyse the possibility to use a PTPT device for electronic equipments cooling and for desktop computer above all. All the previous activity has carried on the experimental test with a big sized apparatus [24] - [29]. The relevant reduction of the scale factor could generate unknown problems and a thermal behaviour really different could be observed. In order to carry out a previous experimental activity on a miniature PTPT, a numerical design of a cooling device has been made.

The PTPT simulator code has been suited for the working fluid used in the apparatus, that is FC72, a low boiling temperature dielectric fluid. This kind of fluid will allow us in future to set up a direct cooling solution too. The evaporator of the PTPT device is the most simple one with a flat exchange surface and a bottom heat regime of heat transfer. The condenser used is an air forced one. The conditions of cooling air are: velocity equal to 2.5 m/s and environmental temperature equal to 30 °C. The dimensional limits considered in order to design all the components of the apparatus are the following. The apparatus must be inserted in a volume of 400 x 400 x 200 mm, which are the external dimension of the most common desktop computer case nowadays. Both A and B-devices are simulated during the tests. For A-device, the delaying tank is inserted into the evaporator volume.

The starting condition of the simulation analysis are fixed by the CPL device developed by Chen et al. [17] for last generation desktop computer, which uses FC72 as working fluid. In this case the heat exchange hot surface is 15.96 x 10^{-4} m^2 (41 x 38 mm Pentium IV processor dimensions) and the maximum heat power transferred is 40 W. The reference condition of the simulation tests are summarized in table (2).

MAIN Starting input data for PTPT simulator CODE			
Evaporator volume	10 x 10^{-6} m^3	Connecting lines internal diameter	4 mm
Accumulator volume	5 x 10^{-6} m^3	H_{tot}	250 mm
Delaying tank volume	4 x 10^{-6} m^3	ΔH_{ag}	100 mm
Hydrosyphon height	23 mm	T_{env}	30 °C
Evaporator liquid volume filling	0.4 %	Cooling air velocity	2.5 m/s
Condenser length	2 m	Heat power rate	40

Table 1 – MAIN Starting input data for PTPT simulator CODE

The main results of the simulation tests are reported in the Figs 3 - 8. The figs 3 and 4 show the temperature trends of the main components of the A and B- PTPT devices respectively. The simulation results point out that the PTPT device can be used as CPU coolers in both the cases. The maximum wall temperature of the evaporator, which is corresponding with the chip temperature, is 65 °C about for both the PTPT devices, while its maximum oscillation is respectively 8 °C for the A-devices and 12.5 °C for the B-devices.

The maximum vapour temperatures in the evaporator for the CPL proposed by Chen in [17] for the same heat power rates and working fluid is about 83 °C, that is 22 °C higher than the simulated PTPT cooling device. Fig. 5 shows the maximum wall temperature increasing versus time when the heat flux is increased. The maximum heat flux removed by the device, keeping the wall temperature lower 100 °C, is 6.3 W/cm^2 about (100 W for Pentium IV heat exchange surface) with heat transfer time period of 128 s. On the contrary the time period in the reference case (40 W) is over 350 s.

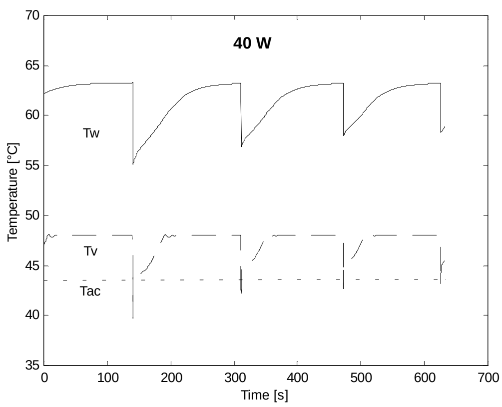

Figure 3 – Temperature diagram for A-device.

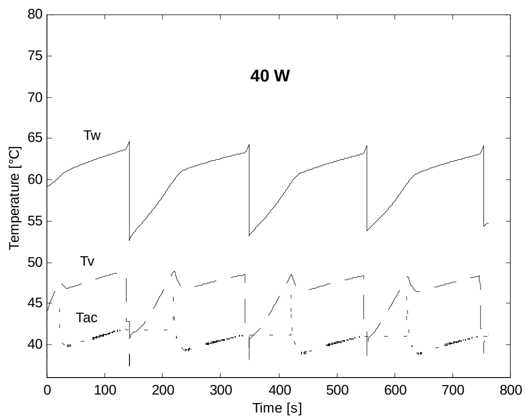

Figure 4 - Temperature diagram for B-device.

Moreover the influence of the liquid mass into the evaporator has been numerically estimated, increasing the liquid filling ratio from 30% to 80% of free volume. Fig. 6 shows as increasing a filling liquid ratio from 30% to 80%, the period time of the heat transport cycle is increasing from 100 to 350 s about, while the wall temperature of the evaporator remains constant.

At last the influence of the distance from the evaporator to the condenser versus ~~on~~ the wall temperature and the heat transport time has been investigated. Increasing the distance from 100 mm till 500 mm the wall temperatures of the evaporator does not vary so much.

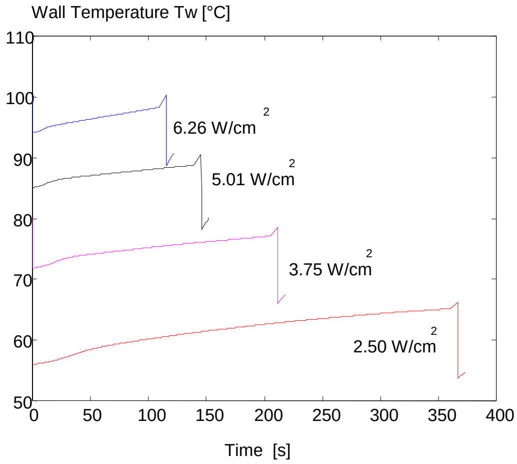

Figure 5 – Influence of the heat flux on the ~~wall~~ evaporator wall temperatures for A-device.

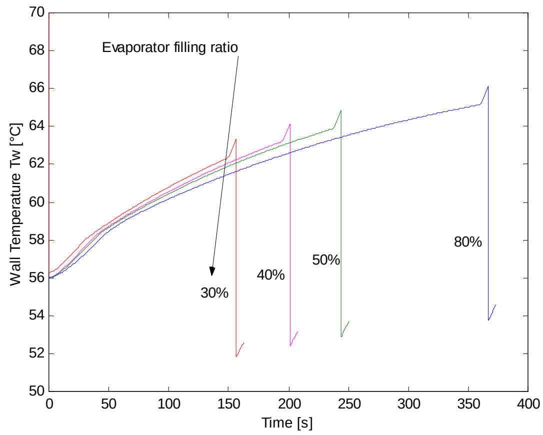

Figure 6 - Influence of the liquid filling ratio on the ~~wall~~ evaporator wall temperatures for A-device..

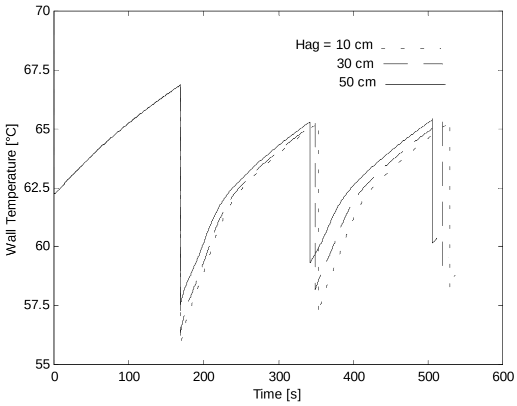

Figure 7 – Influence of the heat flux on the wall evaporator temperatures for A-device.

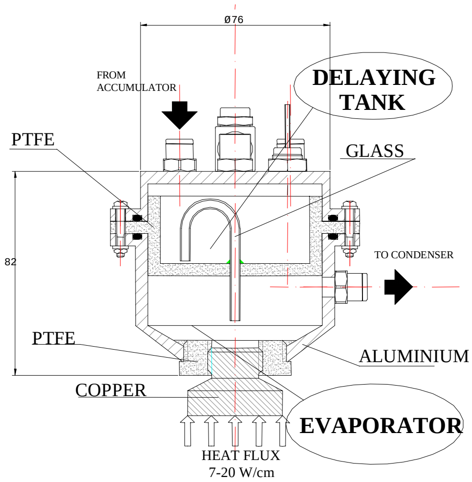

Figure 8 – Evaporator and delaying test.

EXPERIMENTAL SET-UP

The main characteristics of the experimental set-up are determined by the previous numerical ~~activity~~ calculus, which has pointed out as both the PTPT devices are technically well suitable to the electronic equipment cooling. In order to study both the kinds of PTPT devices an hybrid apparatus with a delaying tank and an equilibration line too (Fig. 8) has been realized.

The delaying tank has been realized into the evaporator volume. Fig. 8 shows a diagram of the evaporator and the delaying tank, both in aluminum, while their photo is reported in Fig. 9. The shape and the overall dimensions of the evaporator are determined in order to make its instrumentation easier, and in future it could be surely more compact. The electronic components are substituted with a cylindrical copper dissipator heated with a thermoelectric heater at the bottom. The copper dissipator has been studied with a finite elements commercial code to investigate ~~on~~ its temperature distribution uniformity and ~~on~~ the heat power dissipation rate from the lateral surface, which results lower than 5%. Its flat heat exchange surface is 3.14 cm^2.

In order to keep low the average temperature of the aluminum walls of the evaporator, the copper dissipator has been thermally disconnect to them by a PTFE ring. For the same problem the delaying tank is made in PTFE too. The delaying tank and the evaporator are connected with a glass hydrosyphon, and are monitored by 5 thermocouples and a pressure gauge.

Figure 9 – Evaporator and delaying tank overall dimensions.

Figure 10 – Condenser shape and overall dimensions.

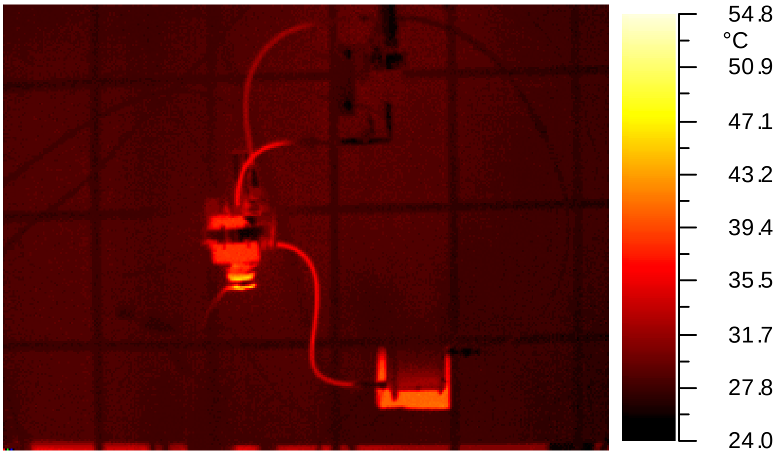

Figure 11 – Infrared themographic photo of the apparatus during its functioning

The condenser is aluminium made and consists of a flat plate 64 x 78 mm sized and 8 mm thick with 22 rectangular fins 28 mm high, 78 mm long and 1.3 mm thick. Inside the flat plate a serpentine groove with a section surface 4x4 mm has been made, as it is possible to note in Fig. 10.

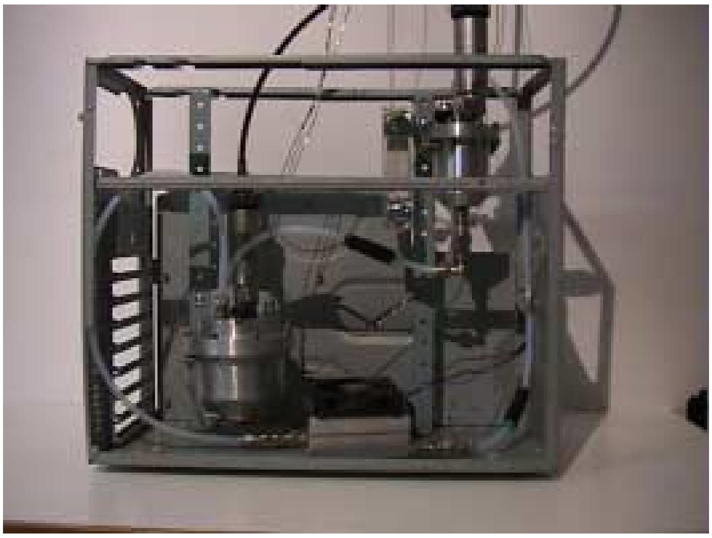

Figure 12 – Experimental setup inserted into a desktop computer case.

The condenser is cooled by a fan with environmental air. The serpentine groove is covered by a Pyrex flat plate 2 mm thick. The accumulator is realised in aluminium too. A level meter is inserted in the accumulator, while two thermocouples measure the vapour and liquid temperatures inside the vessel. All the connection lines are flexible polyethylene pipes with an internal diameter of 4 mm. The check valves used have little size (35 mm long and an external diameter of 15 mm about). All the external

surfaces of the components has been covered with a known emissivity film (ε = 0.95) which allows to control and measure all the temperatures of the loop with a infrared thermo camera. A themographic photo of the device during its functioning is reported in Fig. 11.
All the temperatures and pressures of the device are logged by time with a scanning step of 3 s.
All the components are inserted into a case of a commercial desktop computer. The condenser is located 100 mm under the evaporator, while the accumulator is located 250 mm over the condenser. Figure 12 shows the experimental set up inserted into a case with the following overall dimensions 350 x 430 x 200.

FIRST EXPERIMENTAL RESULTS

The aim of the experimental tests carried out is to observe the functioning of the PTPT cooling device both for A and B kind.
All the experiments are carried out filling the evaporator with $4 \cdot 10^{-6}\,m^3$ of working fluid FC72 at the environmental condition (22 °C). The filling ratio of the loop is about 40%. Also the liquid and ~~the~~ return lines are filled by liquid. After the filling the vacuum is realized inside the loop by a vacuum pump, so that the liquid into the evaporator is at the saturation condition at the starting time. At this moment a heat power rate is supplied to copper dissipator and the thermal behaviour is monitored by time. Firstly it has been investigated the A-device functioning, but it is failed.

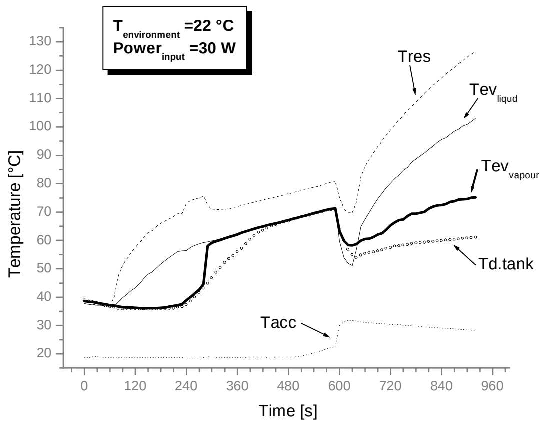

Figure 13 – Experimental start up for A-device

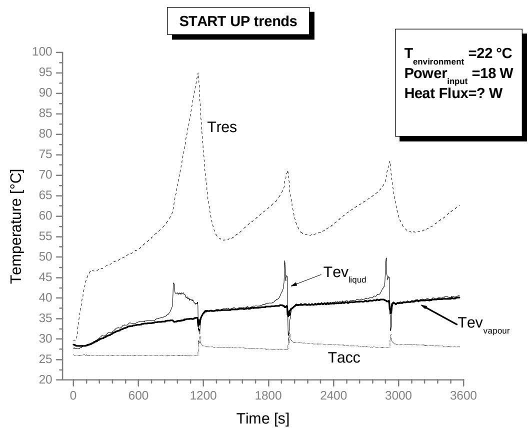

Figure 15 – Temperature diagram for B-device, start up, 18 W as heat power rate.

Fig. 13 shows the start up for a heat power rate of 18 W. As the heat power as supplied to copper dissipator, its temperature (Tres) and the vapour and liquid temperatures of the evaporator increase as the pressure. An heat and mass transport is realised from the evaporator to the condenser where the liquid is collected.
Theoretically, as the evaporator is empty, the pressure decreases till the saturation pressure at the environmental condition, while the accumulator pressure should be higher. Fig. 13 shows as the temperature and the pressure inside the evaporator are decreasing when the evaporator is empty , and at the same moment (after 580 s about from the start) the temperatures of the accumulator (Tacc) is increasing. However, being the accumulator temperature equal to environmental one, the final pressure of the evaporator not is low enough to open the check valve, so that no return of liquid is observed and the overall temperature increases again. The simulation code has pointed out that the minimum temperature of the accumulator should be at least 10 °C higher than the environmental one. A further experimental activity will be carried out on this problem.
On the contrary the B- device has shown a stabilized periodic functioning. Fig. 14 shows that the start up temperature trends in all the components of the loop for an heat power rate of 18 W. It possible to note as the functioning of the device reaches quickly (after 3000 s about) a stabilised periodic regime. However a functioning similar to the regime one is reached after the first heat and mass transport. Fig. 15 shows a stabilized periodic regime for a heat power rate of 18 W. The temperature of the dissipator is oscillating between 55 and 70 °C and the oscillation period time is 1100 s about. The heat flux removed is approximately equal to the maximum heat transfer dissipated by Chen in [17], but the

temperature of the vapour in the evaporator are here 40 °C lower. Fig. 16 shows the same temperature trends for a heat power rate of 30 W (9.55W/cm^2).

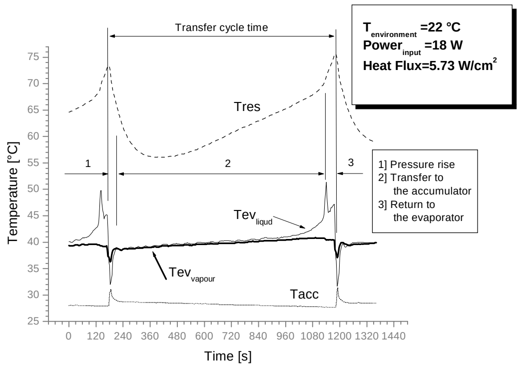

Figure 15 – Temperature diagram for B-device, heat transport regime at 18 W as heat power rate.

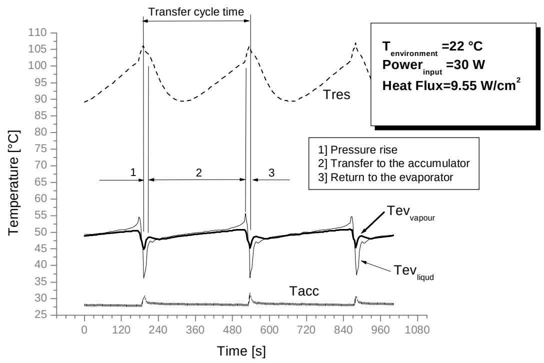

Figure 16 – Temperature diagram for B-device, heat transport regime at 30 W as heat power rate.

The temperature of the dissipator is varying around 100 °C. This heat power rate is really a limit for this device in case of electronic cooling application. However the performance with enhanced surfaces is surely better than the one obtained with plane surface in the dissipator. All these tests show that the B-device PTPT could be used for the electronic equipment without problems, showing thermal performance similar to LHPs or CPLs used for this kind of applications, but with the peculiarity that the condenser is 100 mm under the evaporator.

CONCLUSIONS

This work proposes an experimental set-up to investigate the possibility to use a Pulsated Two-Phase Thermosyphon to cool a desktop computer processor. This kind of devices can operate against gravity with natural circulation and could be a really alternative solution to a fan coolers low performance or to the high cost capillary loops. They were been analysed in a previous activity for an electronic equipment cooling but using a big size apparatus. By means of a calculus code created by the authors in cooperation with MPI and experimentally validated, a miniature experimental apparatus based on a PTPT heat transfer regime has been firstly designed and after experimented. The tests have pointed out that two kinds of PTPT devices could be used. The first one is not functioning if the accumulator temperature is equal to the environmental one. In a further experimental activity this peculiarity will be better investigated. The second kind of PTPT device has been investigated too. On the contrary it has shown a stabilised heat transfer regime with a maximum heat flux removed of 9.55 W/cm^2, with the condenser located 100 mm under the evaporator and without any capillary structure to transport the working fluid. For higher heat power rates, the temperature of the dissipator, simulating the thermal behaviour of the chip, becomes higher than 100 °C. A good qualitative accordance between the simulation tests and the experimental one has been obtained. The experimental tests have however shown as this PTPT can be a really low cost alternative solution for the desktop computer processor cooling, but some experimental investigations had to be made in order to optimise it.

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