Experimental Tests of Mini Heat Pipe, Pulsating Heat Pipe and Heat Spreader under Microgravity Conditions Aboard Suborbital Rockets

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Abstract

Consumer demands for electronic equipment have motivated its miniaturization and power consumption increase, leading to heat concentration problems. Small heat pipes are devices usually considered for thermal management of these systems for many terrestrial applications, including computers, laptops, etc. To guarantee a good performance of small heat pipes in microgravity conditions, the operating characteristics of these devices in this environment must be well understood.
This paper presents an experimental analysis of four two-phase technologies developed in Brazil for the thermal management and heat dissipation of electronics for microgravity conditions which were tested on the laboratory (gravity environment). They are: mini heat pipes, heat spreaders, pulsating heat pipes and phase change material devices (PCM), the last one used to control the heat sink temperature. These devices present not usual geometries. The tested heat pipes have been charged with acetone and methanol. The laboratory results demonstrated that the heat pipes tested present small thermal resistances and that the PCM showed to be a convenient cooling device for microgravity use. The gravity tests will be compared with microgravity results, to be obtained from a launching platform experiment flight, scheduled for 2010.

Key Words: Mini heat pipe, heat spreader, pulsating heat pipe, phase change material.

1. INTRODUCTION

In recent years, the need for electronic components miniaturization is mainly observed in the computer industry, especially for notebooks thermal management. The compactness and high power dissipation density of these devices require efficient cooling methods. Such equipments are employed in many different applications and environments, from home utilities to the International Space Station (ISS) equipment.
In the normal gravity environment, heat pipe can work properly without any kind of capillary structure, if in the vertical position, or assisted by a wick material, if in the horizontal position. On the other hand, the design of these devices for operation in microgravity conditions requires an understanding of their operating characteristics, mainly for space applications. The thermal behavior of the two-phase thermal systems cannot be properly observed in Earth environment because gravity tends to act hard in several fluid mechanic phenomena. Actually, the gravity force can mask some effects, so that when it is decreased or even removed, other forces can assume the control of the fluid mechanics.
In the search for cooling solution alternatives, four types of technologies (mini heat pipes, heat

spreaders, pulsating heat pipes and PCM), developed for the thermal management and heat dissipation under microgravity operation conditions, will be present in this work.
The experiment will be tested aboard an experimental platform to be launched in the Maracati Mission of the VSB-30 rocket, from the Alcantara Rocket Launch Center in Brazil, in July 2010. Around six minutes of microgravity testing time will be supplied by the Platform. Actually this launching, planned to happen in September 2009, was postponed due to the launch pad rebuilding.

2. Heat pipe technologies

2.1 Mini heat pipes

According to the previous works [1, 2 and 3], the wire mini heat pipe thermal performance can be considered known for typical flat straight geometries. But some applications require the employment of different geometries. For example, in several small laptops, curved heat pipes must be designed, to adjust to a specific geometry. In this case, the effect of bending in the thermal performance of the heat pipe must be well known, before its application. To study the influence of curves in mini heat pipe performance under gravity and microgravity conditions, a "S" shape wire mini heat pipe, shown in Figure 1, was manufactured.
Many different techniques can be employed for the fabrication of micro or mini heat pipes. One of them consists of brazing aluminum wires between plates. This procedure can block partially the grooves formed between the wire and plates. In this work, the copper diffusion welding, a more sophisticated welding technology was used in the fabrication of the "S" shaped heat pipes [see 1, 2, 3 and 4].

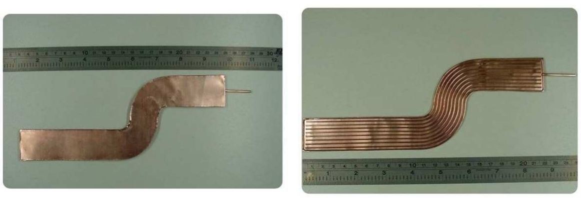

Figure 1: "S" shaped mini heat pipe.

The second technology applied for the fabrication of the mini heat pipes tested is powder sintering wick structure. As it can be seen in Figure 2, the upper and bottom plates of the MHP are covered by a thin layer of sintered copper powder porous wick. Three solid copper wires are placed in the middle of the MHP to provide a vapor region and the necessary structural strength. The diffusion welding technique was employed to seal the device.

Figure 2: Sintered mini heat pipe.

2.2 Pulsating heat pipe

The next technology tested is the pulsating heat pipe (PHP). PHP is a special type of heat pipe which works based on the displacement of the working fluid created by the evaporation and condensation process, working in a non-equilibrium heat transfer state. The device manufactured for this study consists of a long copper capillary tube bent in a planar geometry (see Fig. 3) into 16 turns and charged with acetone in a volume ratio of 50%. As it does not have wicks, the vapor formed in the evaporator concentrate in several plugs, which, due to their density difference, moves to the condenser region displacing the liquid over it. Therefore, the gravity can have major influence in its performance [5].

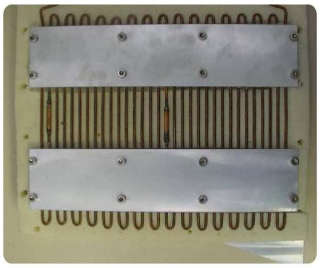

Figure 3: Pulsating heat pipe.

2.3 Heat Spreaders

In electronic applications, a small hot spot can cause an uneven heat flux distributions, decreasing the performance of components. In some cases, to overcome this issue, just spreading the heat can be enough to control the component temperature.

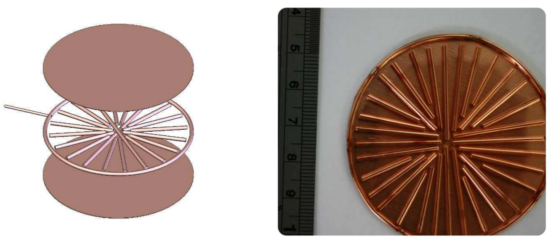

Figure 4: Heat spreader.

The heat spreader proposed in this study is formed by radial grooves manufactured using wire/plate diffusion welding technique (See Figure 4). Its dimensions are: 52 mm of diameter and 2 mm of thickness.

2.4 Phase change material

According to the recent microgravity experiment results [2] in rockets similar to the one to be employed in the next microgravity experiment, the temperature inside the payload model turned out to be higher than expected, due to the excessive air friction between the rocket and the atmosphere and due to heat produced by other experiments in the same module. In this way, to overcome this issue and to keep the sink temperature at steady conditions, a phase change material (PCM) device was introduced.

3. EXPERIMENTAL ANALYSIS

The experimental hardware dimensions are restricted due to the limited space inside the rocket platform. The experiment described in this work is composed by four models identified as TCM A, B, C and D as described in Table 1.

Table 1: Equipment description.

Name	Description	Dimensions LxWxH (mm)	Mass (kg)
TCM-A	MHP- S shaped	285x110x210	6,03
TCM-B	PHP	270x90x250	7,04
TCM-C	Heat Spreader and MHP – sintered power	200x80x160	2,5
TCM-D	Data acquisition system	140x146x230	5,77

One of the major problems in this experiment was the space available, since the payload rocket module basically consists of a barrel with two lids, which works as experiment mounting panels (see Figure 5).

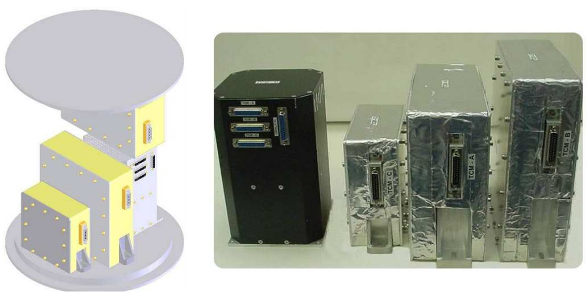

Figure 5: Payload module and the experiments.

3.1 TCM-A and TCM-B modules

The TCM-A and TCM-B modules have the same design characteristics, where the major difference is the overall dimensions, as illustrated in Figure 6.

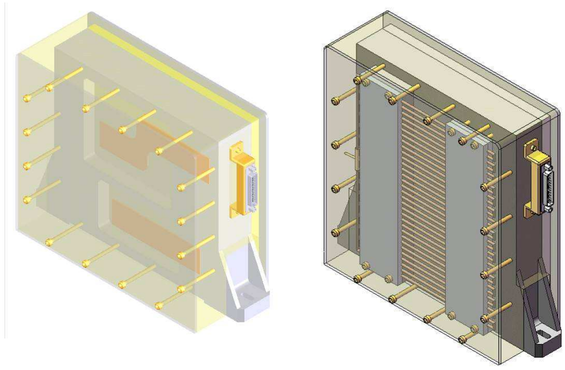

Figure 6: TCM-A and TCM-B modules.

In these modules, an aluminum support was built to fasten the entire device in the rocket platform. Two insulation plates (polyurethane foam) are used to sandwich the heat pipes. This entire assembly is fixed to an aluminum block. Just a small part of the heat pipes (condenser) are attached to the heat sink. The aluminum block absorbs the generated heat, warming up in transient condition, as the test time is very short. Fans cannot be used in the platform due to the vibrations during the launching.

Some thermistors of 10 kΩ were placed in each heat pipe to measure the temperature distribution, as can be seen in Figure 7. The thermistor temperature measurement uncertainty is ± 2ºC.

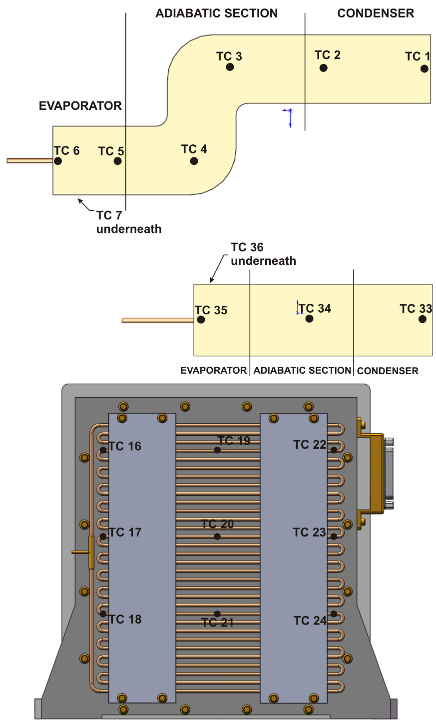

Figure 7: TCM-A and B thermistors position.

3.2 TCM-C module

TCM-C hardware was built in the same way as explained above for the modules TCM-A and B. The most important difference is in the heat sink. Instead of having just the aluminum block, sodium phosphate dibasic dodecahydrate will be used as an additional heat sink, absorbing the heat generated by the devices and keeping the temperature controlled (see Figure 8). This salt has a melting point of 35° C.

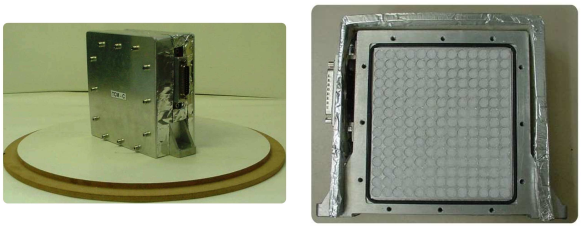

Figure 8: TCM-C hardware.

The temperatures along the device are monitored by means of thermistors (see Figure 9) that are attached to on the heat spreader.

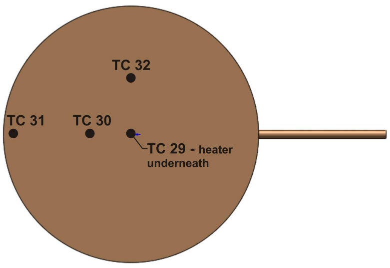

Figure 9: TCM-C thermistor positions.

3.3 TCM-D module

A data acquisition system was designed especially to monitor the set-up temperatures during the flight, under microgravity conditions. An aluminum box was used to accommodate the data acquisition system (see Figure 10), which is composed of the following equipments: PC/104 board, data acquisition board, DC/DC converter, power control board, batteries and memory card.

Figure 10: Data acquisition module.

The PC/104 is basically a computer (equivalent to Pentium III, 800MHz). A MSDOS operational system is used to manage the files of the memory card. The control, read and acquisition programs were developed in C++ language. The software controls great part of the experiment operation. All the data are saved in the memory card and also transmitted by telemetry. Three nickel-metal hydride battery packs, in a total of 36 V and 5Ah, are used to provide electricity to the data acquisition system as well as the heat pipes skin heaters.

Due to: the short period under microgravity condition (approximately 6 minutes), the battery capacity and the platform power restrictions, only one power step will be supplied for each heat pipe, by means of electrical heaters. Table 2 describes the power applied to each heat pipe.

Table 2: Mini heat pipe characteristics

Module	Heat pipe	Volume (ml) [fluid]	Power (W)
TCM-A	MHP S	1 [methanol]	10
	Sintered MHP	0.5 [methanol]	8
TCM-B	PHP	3.77 [acetone]	20
TCM-C	Heat spreader	0.2 [methanol]	7
	Sintered MHP	0.5 [methanol]	10

3.3 Test procedure

A control box is used to control the experimental modules. Due to the microgravity restrict time the power applied to PHP and PCM must be turned on 20 minutes before the lift-off to guarantee the PHP startup and PCM melting point. Temperatures data will be sent by RS 485 protocol to a laptop throughout an umbilical cable. Once the rocket is launched, the lift-off sign will turn on and the data acquisition system will start to save data into the flash memory and send them by telemetry, at the same time. Approximately 1 minute after the lift-off, the microgravity condition will be reached and an electrical signal will power up the rest of the heat pipes.

During the lift-off step, the cables that will be connected to the rocket umbilical will be removed, commuting the experiment to the automatic mode and using energy from the batteries. For the laboratory tests, the same procedure was followed.

4. EXPERIMENTAL RESULTS

The test results under gravity conditions are presented in this section. Figure 11 shows the performance of the "S" shaped mini heat pipe. Figure 12 shows the PHP results. From this last figure, one can observe that it takes a while for the temperatures to start to oscillate and that this oscillation is more observed in the adiabatic section. As illustrated in both Figures 11 and 12, the devices did not reach the steady state conditions, due to the small capacity of the aluminum heat sink, which keeps heating up while they receive heat from the experiments. Even though, the performance of this heat pipes are almost the same when their results were compared with the laboratory results, using the cooling bath apparatus as a heat sink.

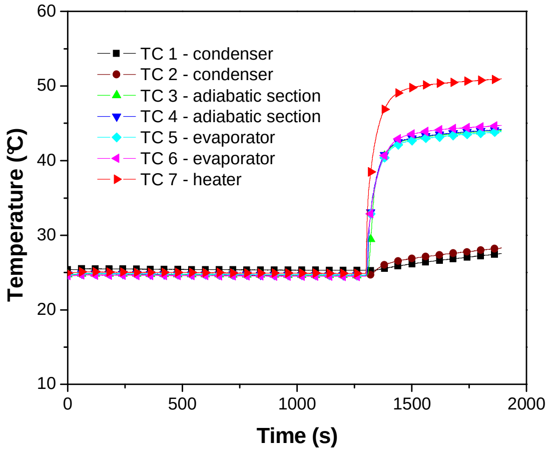

Figure 11: Gravity temperature profile of the “S” mini heat pipe.

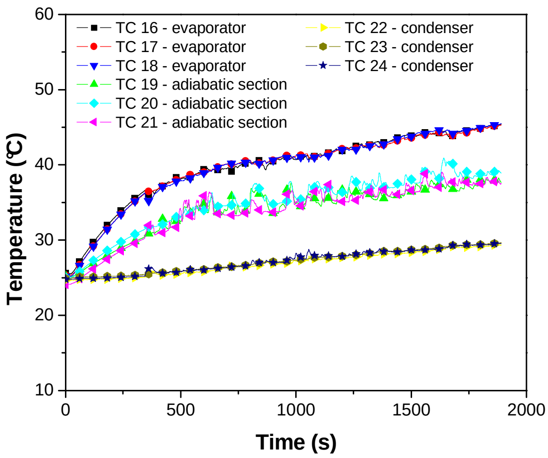

Figure 12: Gravity temperature profile of the PHP.

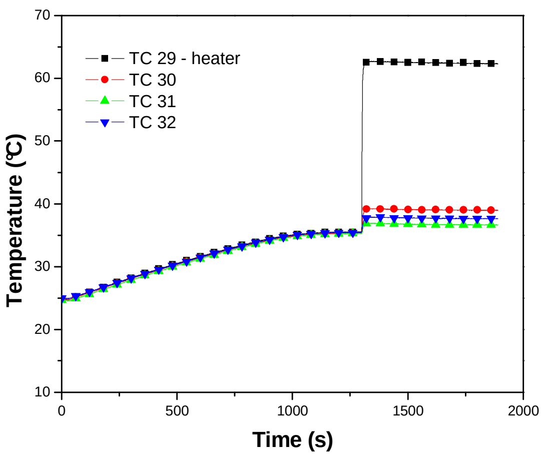

Figure 13: Gravity temperature profile of the heat spreader using PCM in the heat sink.

Figure 13 shows the heat spreader results. As can be observed, during the first 20 minutes (around 1250 seconds), power was applied to the aluminum block heaters in order to melt the PCM. As soon as the steady state is reached, heat is added to the device. Similar temperatures are observed by the thermistors distributed along the heat spreader, showing an even temperature distribution.

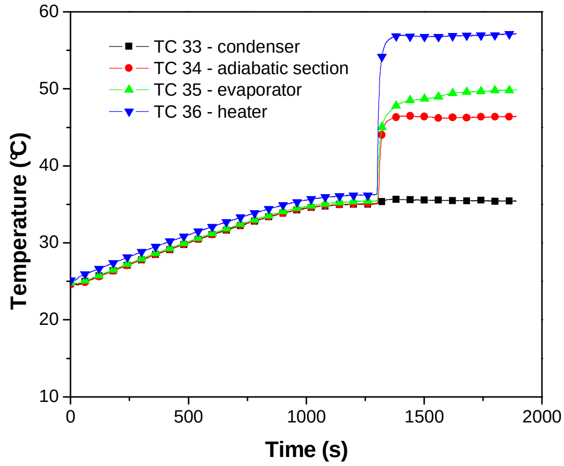

Figure 14: Gravity temperature profile of the sintered mini heat pipe with PCM in the heat sink.

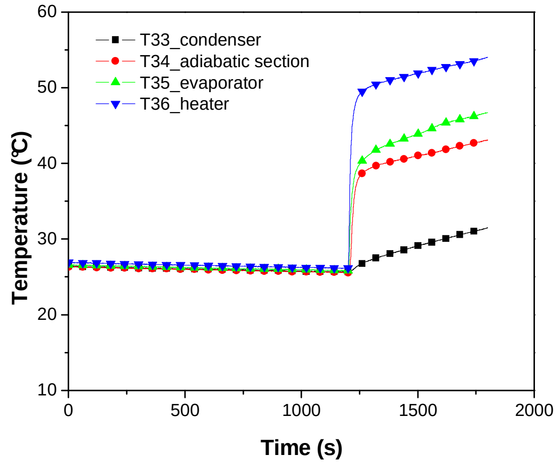

Figure 15: Gravity temperature profile of the sintered mini heat pipe without PCM in the heat sink.

Comparing Figures 14 and 15, one can see that the PCM, used as an additional heat sink for the sintered MHP experiment, stabilizes the temperature distribution, allowing the system to reach the steady state conditions.

4. CONCLUSIONS

The heat transfer performance of four types of heat pipes have been investigated experimentally under gravity conditions. Unfortunately the microgravity test was postponed and so the comparison of gravity and microgravity

experimental results could not presented in this paper.
PCM showed to be a good alternative as heat sink for this kind of experiment to be tested aboard sounding rockets. The temperature profiles indicate that the use of the aluminum block as the heat sink was not enough to allow the system to reach steady state conditions.
The observed thermal resistances of the devices tested in laboratory are small, showing that the technologies applied are efficient and that these heat pipes can be used as an electronic equipment thermal control devices for gravity and very probably for microgravity applications.

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