14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

WIRE MINI HEAT PIPE UNDER MICROGRAVITY CONDITIONS

Kleber Vieira de Paiva
Marcia B. H. Mantelli
Heat Pipe Laboratory (Labtucal)
Mechanical Engineering Department
Federal University of Santa Catarina UFSC
P.O. Box 476, Florianópolis, 88040-900, SC, Brazil
Phone: +55 48 2342161, FAX: +55 48 234 1519
Email: kpaiva@labsolar.ufsc.br
marcia@emc.ufsc.br

Raul Gohr Jr.
Marcelo de Assis Corrêa
Welding Laboratory
Mechanical Engineering Department
Federal University of Santa Catarina UFSC
P.O. Box 476, Florianópolis, 88040-900, SC, Brazil
Phone: +55 48 2342161, FAX: +55 48 234 1519
Email: rgj@labsolda.ufsc.br

ABSTRACT

The mini heat pipe considered in this work consists of the union of cylindrical cooper wires between two thin copper plates. The edges formed between the wire and the plate provides the capillary pressure. This device was tested under microgravity conditions, with the objective of determining the lack of gravity effect on the heat transfer capacity of the device, by comparison with its performance under gravity. Two wire mini heat pipes were tested under microgravity conditions aboard the International Space Station (ISS) by the Brazilian Cosmonaut Marcos Pontes during the 13th Expedition of the Soyuz rocket to the ISS. The Mission was part of the Brazilian Space Agency Microgravity Program, in the frame of a partnership with Energia/Roscosmos Russian Agency. The flight took place on March 30th in a Soyuz rocket in Baykonur Cosmodrome – Kazakhstan. A compact data acquisition system was developed to measure and save the temperature distribution along the mini heat pipe. The heat was released to the evaporator by means of an electric heater attached to the wire mini heat pipe surface and was removed from the condenser by fin surfaces, through which air is blown by fans. Results indicated a good agreement between the microgravity and gravity results, showing the efficiency of the device in the thermal management of equipment under microgravity conditions.

KEY WORDS Mini heat pipe, microgravity

1. INTRODUCTION

Mini heat pipes are devices usually considered for thermal management of electronics for many terrestrial applications, including: computers, laptops, etc. In the normal gravity environment, heat pipes can work properly in the vertical position without any kind of capillary structure. If in the horizontal position, they will need a wick structure to allow the return of the condensate to the evaporator. The design of satellite thermal control systems requires an understanding of heat pipe operating characteristics under microgravity environment. The thermal behavior of heat pipes can not be properly observed on Earth environment because gravity tends to have great influence in several fluid mechanics phenomenon. Thus, the gravity force can mask the effects of some parameters. In the decrease or lack of gravity, other forces can assume the fluid mechanics control (Gabriel, 2002).

Some phenomena related to capillary force in wick structures are directly connected to surface tension variation, specially when the gravity is reduced.. In specific case of heat pipes, other phenomena can influence their thermal performance, such as: liquid blockage due to nucleation of bubbles and weak capillary force to keep the liquid into the grooves.

The mini heat pipe used in this study was developed using the diffusion welding procedure as described in Mantelli et al. (2002). The working fluid flows through channels formed by welding parallel cooper wires sandwiched between two thin copper flat plates (Wang and Peterson, 2002). In the present work, a mini wire heat pipe charged with water, designed to be tested under microgravity conditions, is presented. Constructive aspects of this development are exposed as well as experimental comparison of the results obtained under gravity and microgravity conditions. The device was tested aboard International Space Station on beginning of April 2006 during the 13th Expedition.

2. FABRICATION PROCESS

The mini heat pipes proposed to be tested in this work were fabricated using the welding diffusion procedures. When a plate and a cylinder touch each other, a very sharp edge between then are observed. If these surfaces can be welded without blocking the groove, these edges can work as efficient porous media for heat pipe applications. The diffusion welding is a welding technique able to provide such grooves. The mini heat pipe tested in the present work has 100x30x2 mm of dimensions and 8 parallel copper wires welded between two thin copper sheets, of 0.2 mm of thickness. Another wire goes round of the device to create a board and seal the pipe. The distance between two wires is approximately 2 times the wire diameter of 1,5 mm, as it can be seen in Figure 1.

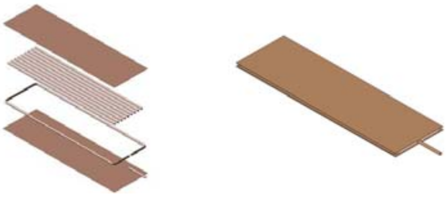

Figure 1. Mini heat pipe sketch.

After the fabrication and cleaning process is concluded, the pipe is leak tested by means Edwards Leak Detector equipment and finally charged. The charge procedure is the following: the mini heat pipe is linked to the vacuum pump by a small tube (Tygon tube). After the vacuum is established, especial clamp closes the tube and the adequate amount of working fluid (usually very small) is slowly injected into the tygon tube using a micro syringe (Insulin syringe 1 cc). After that, the mini heat pipe is sealed. The vacuum inside the mini heat pipe pull the liquid inside the heat pipe.

Two mini heat pipes had their performance validated under microgravity conditions. The difference between them is only the amount of deionized water. One of them will be charged with approximately 0,5 ml and the other one with 0,3 ml. Other fluids were not tested because the safety requirement of Space Station. If they were used, a tri barrier would be required to guarantee no leak.

2. EXPERIMENTAL ANALYSIS

2.1 Centenario Mission – Project MHP

The MHP experiment consists in a unique module, as can be seen in Figure 2. It can be separated in two parts: heat pipe support (HPS) and data acquisition system (DAS).

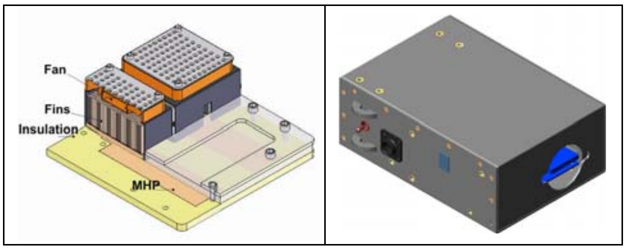

Figure 2. HPS and DAS sketches.

The HPS was placed on the DAS. Inside the HPS are located the two mini heat pipes, charged with deionized water, volume of 0,5 ml and 0,3 ml. An aluminum support was built to fasten the entire device. Cork plates are used to insulate the system from the environment and a special copper covering sheet was introduced to protect the insulation material from any damage.

As usual, the mini heat pipe presents three different regions: evaporator, adiabatic section and condenser. Heat is added to the evaporator by means of a skin heater attached over a length of 20 mm of the heat pipe. The adiabatic section, of 50 mm of length, is thermally insulated from the environment. Heat is removed from the condenser by a copper fin cooler, installed over a length of 30 mm. To ensure good contact, thermal grease (Dow corning 304®) will be introduced between cooler fan and mini heat pipe and between the heater and the evaporator.

Type T thermocouples (Omega® - TT-T-040) are used for monitoring the temperatures distribution. They are attached to the surface by means of Kapton tapes and are directly connected to the DAS. The mini heat pipe charged with 0,5 ml received 4 thermocouples, one for each section and other one over the heater. The mini heat pipe charged with 0,3 ml received 3 thermocouples, one in the evaporator, one in the condenser and the other over the electrical heater.

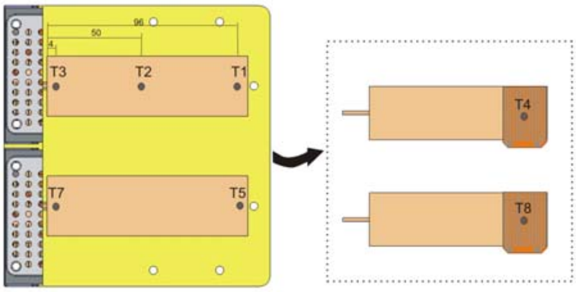

Figure 3. Thermocouple positions

Two thermocouples are installed over the heaters and over the evaporator and are connected to the data acquisition system, to monitor the temperature of the device. The software will switch off the system, if the heater or evaporator temperatures, of 100^{o}C and 80^{o}C, are reached respectively. The thermocouple temperature measurement uncertainty is ± 1,7ºC. The heat loss was calculated as less than 8%. The input power into the electrical heater is controlled by means of software. In case of any off nominal situation, the thermocouple of the heater will actuate, turning off the electrical heaters. To guarantee the redundancy of the system, a second thermocouple, located at the evaporator, will also protect the system switching off the heaters. Due to the limitation of space and weight, the data acquisition system could not be large and the total number of thermocouples was restricted.

An aluminum box with 200x140x74 mm is used to accommodate the data acquisition system, which is composed of the following equipments: PC/104 board, data acquisition board, cold junction compensation board, DC/DC converter, power controlled board, digital/analogical converter board, inrush and fuse board, mini fan to cool the electronic components and a memory card.

The PC/104 is basically a computer (equivalent to Pentium II, 400MHz). A MSDOS operational system is used to manage the files of the memory card, which is the same as used in digital cameras. The control, read and acquisition programs were developed in C++ language. The interface between the astronaut and the experiment was developed in the most elementary way possible, through a power switch and a display. The software controls the most part of the experiment operation. All the data are saved in the memory card, which was the only component that returned to Earth. It was also part of mission a NOMEX$^{®}$ bag, where the MHP module was placed to be carried until the Station and a power cable with bonding wire to connect the experiment to the Station electricity (28 VDC ± 1V). Figure 4 shows all the components of the MHP experiment.

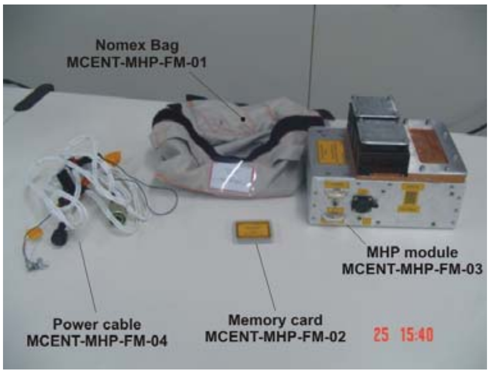

Figure 4. The components of MHP experiment.

2.2 Experimental procedure

In orbit, the software controlled the power input and the time for the experiments. 4 cycles of tests, corresponding to one day of tests, were conducted.

Two configurations were run, according to the power step increase and the duration of each cycle. To guarantee the data, in case of failure, each cycle was repeated once. Each cycle takes place in different days, which were distributed along the 8 days of the astronaut in the ISS. Table 1 describe the duration of the cycles. This approach was adopted to ensure available time for the mini heat pipe to reach steady state. In each cycle, the two mini heat pipes were tested, individually. Power supply for the first mini heat pipe was turned on. After the first mini heat pipe had been tested, its power was switched off and the heater of the second mini heat pipe (charged with a different amount of deionized water) was switched on.

Table 1. Time cycle description

	TOTAL TIME (s)/(h)
1º Cycle	10200 / 2,84
2º Cycle	9000 / 2,5
3º Cycle	10200 / 2,84
4º Cycle	9000 / 2,5

To start the tests, the crewmember inserted the memory card and after, pressed a button located in the DAS module. As soon as he pressed the button, the PC104 board, data acquisition and the cooler fans were activated. Before he turned the electrical heaters on, there is a waiting time of 10 minutes to settle down the system. A display indicated the data acquisition activity. A waiting time of 20 minutes was set between the first and the second tests. After all power steps were set and after the cycle is completed, the data acquisition saved the data. Then, the electrical supply to the heaters was interrupted, indicating in the display that the astronaut could turn off the system, including the cooler fans and PC104 board, pressing the same button. The software was develop to avoid any crewmember mistake; if, for instance, the astronaut accidentally turn off the system, the software would automatically save the data. In this case, the astronaut would press the button again to re-start the cycle from the beginning. The software was adjusted for saving the data information just in the end of each cycle. During the cycle, the crewmember could be involved with other activities, because the experiment runned automatically.

3. RESULTS

The first evaluation of the microgravity results indicated that the MHP module work perfectly during 4 days of tests. Moreover, the comparisons with results at laboratory have shown that mini heat pipe worked very well under microgravity conditions. The major difference between the test conditions in both situations (microgravity and laboratory) is the room temperatures which could not be set in the same level. Actually, as the heat pipe cooling was through forced convection, the room temperature influences very much the condenser heat transfer and consequently, the mini heat pipe temperature level. The astronaut Marcos Pontes reported that the room temperature was set to 22 ºC, but the experiment was located near of the air conditioning outlet, so it is possible that the room temperature was lower. Due to security requirements, it was not possible to place any kind of wire or transducer outside of the equipment, to measure the room temperature. On the other side, the laboratory tests were conducted in a humidity and temperature controlled chamber at INPE (Brazilian Space Research Institute). Some temperature levels where adopted: 20ºC, 25ºC, 28ºC and 40ºC, not exactly the 22ºC observed at the ISS. Figure 5 shows the evaporator and condenser temperature levels for gravity (full lines) and microgravity (dashed lines) tests for a mini heat pipe charged with 0,5 ml.

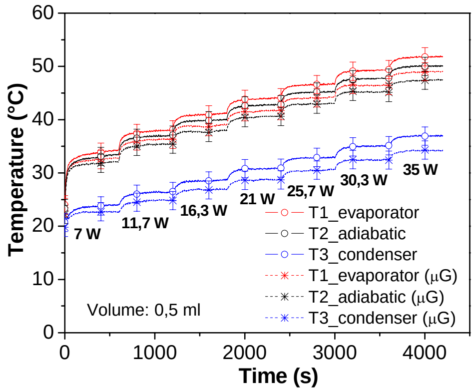

Figure 5. Temperature distribution under gravity and microgravity for 0,5 ml mini heat pipe.

The performance of the mini heat pipe can be associated with its capacity to transfer heat power from evaporator to condenser. The overall thermal resistance represents very well this parameter. It is defined as the ratio between the difference of evaporator and condenser temperatures and the power input. In Figure 6, the thermal resistances for a 0,5 ml mini heat pipes tested under microgravity and gravity conditions is compared. This figure shows that there is no significant difference between the results; which confirms that the temperature difference observed in Figure 5 is due to the room temperature difference. In addition, in the same Figure 6, it can be observed that the overall resistance showed to be approximately 9,5 times that without working fluid, for 35W.

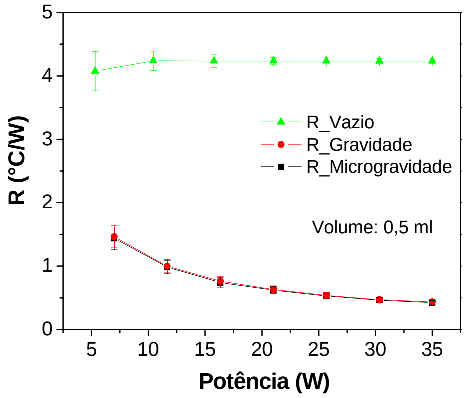

Figure 6. Overall resistance as a function of the power input for 0,3 ml mini heat pipe.

Unfortunately dry out condition was not reached due to two reasons: limitations in the power control system and maximum power available for the Brazilian experiments, which was limited to 100W. It should be noted that the data acquisition, the control system and the three mini fans used to cool the system also use electrical energy. On the top of this, at least two Brazilian experiments were tested at the same time.

The plots presented in Figures 7 and 8 show the thermal performance of mini heat pipe charged with 0,3 ml. of water. The comparison between mini heat pipes charged with 0,3 and 0,5 ml of water, shows that the 0,3 ml heat pipe presented higher temperature levels.

It was expected that the mini heat pipe with less water would reach the dry out point for the test conditions of this work. The laboratory experiments showed that dry out limit in the mini heat pipe charged with 0,3 ml was approximately 35 W. The dry out is verified by the fact that the steady state conditions were not reached in this case.

.

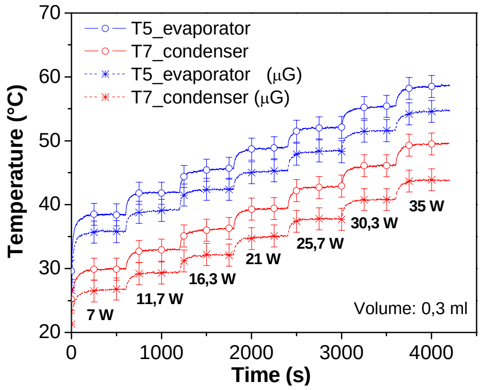

Figure 7. Temperature distribution under gravity and microgravity for 0,3 ml mini heat pipe.

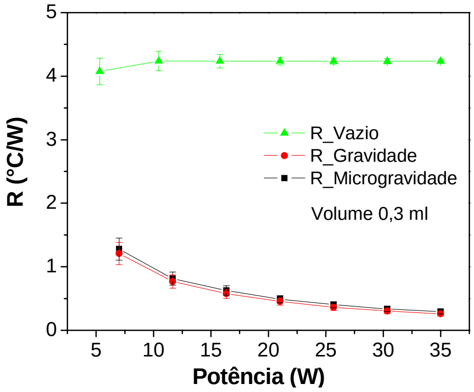

Figure 8. Overall resistance as a function of the power input for 0,5 ml mini heat pipe.

However, this fact was not clearly observed during microgravity tests, mainly due to the difference of the heat sink (room) temperature at the condenser section. In the laboratory, the heat exchanger, in the condenser section, is in direct contact with the cooling fluid, allowing a better control of the condenser temperature, while, in the microgravity experiment, room air was used to dissipate the heat using cooler fans.

In other to ensure available time for the system to reach steady state conditions, another test cycle was conducted. In this case, to keep the total test time the same, the number of power steps were decreased (from seven to four) while the difference between two power steps was increased. Larger times were allowed to each power step, for two reasons: to observe the wick structure behavior under microgravity conditions and to observe if the onset of dry out, specially for the mini heat pipe with low level of working fluid. As already mentioned, the microgravity could bring some undesirable effects to the system thermal performance, such as bubble nucleation under microgravity.

As illustrate in Figure 9 the temperature distribution, for the 0,5 ml mini heat pipe, does not change with time and remains practically the same as Figure 5.

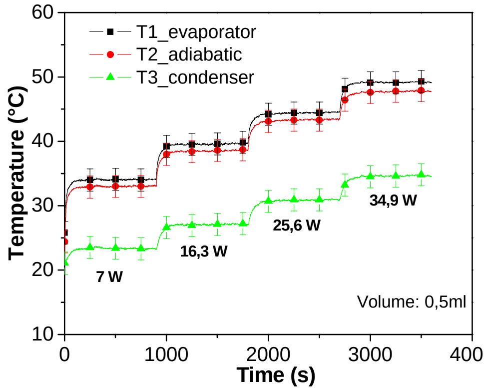

Figure 9. Temperature distribution under gravity and microgravity for 0,5 ml mini heat pipe.

Figure 10 presents the 0,3 ml mini heat pipe results. It can be observed that the temperature distribution of the evaporator sections at the last step is not constant, indicating a possible onset of dry out.

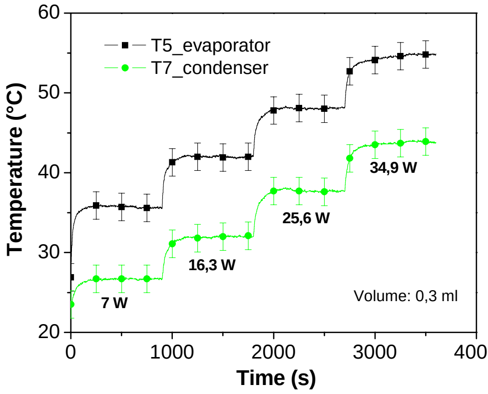

Figure 10. Temperature distribution under gravity and microgravity for 0,3 ml mini heat pipe.

CONCLUSIONS

The heat transfer performance of the mini heat pipe charged with different amount of water has been investigated experimentally under gravity and microgravity conditions. The data showed the efficiency of the device for the thermal management of equipment under microgravity conditions. Although dry out limit was not completely reached, the increasing trend in the temperature distribution of the evaporator indicated a dry out onset, which level is upper than 35 W. The expected effect of larger concentration of liquid in the inferior grooves under gravity, which could reduce the capillary pump performance, or did not occur or had been compensated by a higher efficiency of the fluid evaporation under gravity. Bubbles nucleation could be a restriction factor in the performance of mini heat pipe under microgravity, once there is no separation, by buoyancy, of the vapor phase from the liquid phase. This could imply in a premature dry out in evaporator section due to bubbles stagnation in this region. However, as illustrated in the tests under microgravity, there is no overheating of the pipe at any moment, showing that this event did not occur.

REFERENCES

1. Gabriel, K.S., Microgravity two-phase flow and heat transfer: What have we learned?, 12th *International Heat Pipe Conference*, Moscow-Kostrona-Moscow, Russia, May 19-24, pp 35-41, 2002.
2. Launay, S.; Sartre, V.; Mantelli, M.B.H.; Paiva, K.V., Investigation of a wire plate micro heat pipe array, *International Journal of Thermal Sciences*, vol. 43, Issue 5, pp 499-507, May 2004.
3. Mantelli, M.B.H., Buschinelli, A.J.A., Nascimento, R.M., Paiva, K.V., 2002 Diffusion welding of wire micro heat pipe arrays, *12th IHPC*, Moscow-Kostrona-Moscow, Russia, May 19-24, 6p. .
4. Peterson, G.P., 1994, *An Introduction to heat pipes. Modeling, Testing and Applications*, Wiley Interscience, New York - USA.
5. Wang, Y.X., Peterson, G.P., 2002, Analysis of Wire-Bonded Micro Heat Pipe, *Journal of Thermophysics and Heat Transfer*, Vol.12, No.3, pp 346-355.