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ANALYSIS OF THE THERMAL PERFORMANCE OF A BRASS MICRO HEAT PIPE ARRAY

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Abstract. Micro heat pipes are devices that work by transporting heat through the phase change of a working fluid inside of an enclosure that has acute angles in its cross section to pump the liquid by capillary effect. The possibility of different combinations of micro heat pipes parameters, such as material, dimensions, geometry, inclination, filling ratio, working fluid type, led to a wide number of studies through the past decades. Therefore, a brass micro heat pipe array was analyzed in the present study. The array consisted of 40 triangular micro channels with 500 μm side length, 105 mm long and 500 μm interchannel spacing. R134a was utilized as working fluid. The thermal performance was measured by values of effective thermal conductivity and thermal resistance of the filled and empty array. The micro heat pipes enhanced the heat transport of the system.

Keywords: micro-heat pipe, phase change, heat transport, cooling method.

1. INTRODUCTION

The development of electronics equipment aims on the miniaturization and improvement of their functionalities. It is possible to notice this trend on notebooks, smartphones, tablets, CPUs and others during the past decade. When it comes to the thermal management of these devices, the heat dissipation increased considerably, due to the space constriction and the high heat flux generated. Single-phase systems, composed of a pump to move the liquid through the system and dissipate the heat, or some conductive materials are becoming insufficient and not advantageous to withstand these high thermal loads in such small devices.

A solution to fulfill the need for a compact and efficient system as a cooling method for electronic components was presented by Cotter on 1984. As the first author to propose the concept of micro heat pipes, Cotter defines these devices as heat pipes reduced in scale linearly in all dimensions, wickless, with noncircular cross section, in order to provide the capillary effect to pump the liquid by the acute angles of the geometry. Micro heat pipes (MHPs) are so small that the mean curvature of the vapor-liquid interface is comparable in magnitude with the hydraulic radius of the total flow channel. The heat is transported by the latent heat of the working fluid enclosured inside of the MHP. The advantages of MHPs on cooling purposes are the capacity of transporting a heat load several times greater than single-phase systems, the absence of a pumping system and the absence of vibration. The goal of fabricating MHPs is to improve the effective thermal conductivity in respect to the thermal conductivity of the base material.

Several studies were performed from the past decades, relating MHPs with different geometries, such as trapezoidal (Babin *et al.*, 1990; Peterson e Ma, 1999), triangular (Peterson *et al.*, 1993; Badran *et al.*, 1997; Le Berre *et al.*, 2003; Launay *et al.*, 2004), rectangular (Peterson *et al.*, 1993; Dean *et al.*, 2012), star grooves and rhombus grooves (Kang e Huang, 2002), and with different combinations of working fluids, dimensions, heat input and other experimental parameters.

In this study, a MHP array with triangular grooves was analyzed. Brass was utilized as substrate and R134a as working fluid.

2. METHODOLOGY

The aim of this study is to analyze the effective thermal conductivity and thermal resistance of a brass MHP array. A comparison between values of effective thermal conductivity and thermal resistance of the empty and filled array was performed. The empty array means that the heat is being conducted by sensible heat through the brass. A thermal circuit was developed and the effective thermal conductivity and thermal resistance for each case were calculated.

The brass MHP array has 40 equilateral triangular grooves with 500 μm side, 433 μm depth, 105 mm long and 500 μm interchannel spacing. The dimensions of the brass wafer are 131 mm long, 50 mm wide and 3 mm thick. For this array, one channel in common with 2 mm wide and 433 μm depth was designed at the condenser for the filling of working fluid, as showed in Fig. 1. An acrylic wafer was placed above the channels in order to allow the visualization of the MHP cycle. Polyacetal, aluminum and screws were utilized to seal the array. The assembly is shown in Fig. 2.
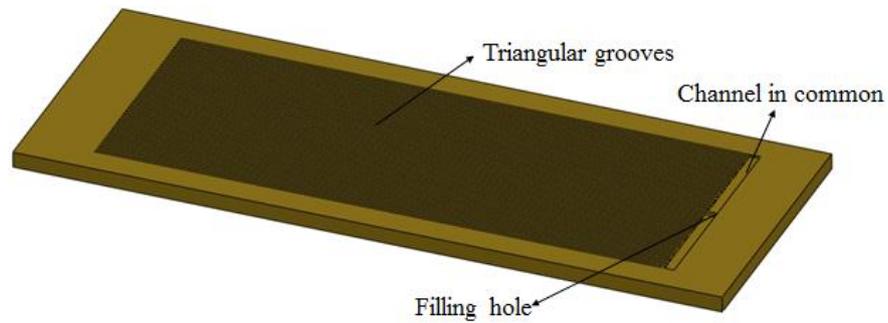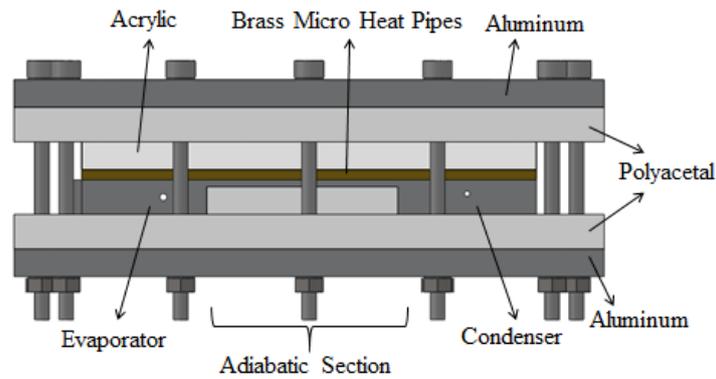

Figure 1. Brass micro heat pipe array.

Figure 2. Assembly of the micro heat pipe array.

The thermal loaded in the evaporator was provided by an electrical resistance. The condenser was cooled by cold water, which was distributed in a gallery of channels within this section, as showed in Fig. 3. The water was cooled by a thermostatic bath, which kept the water with the temperature slight above 0 °C.
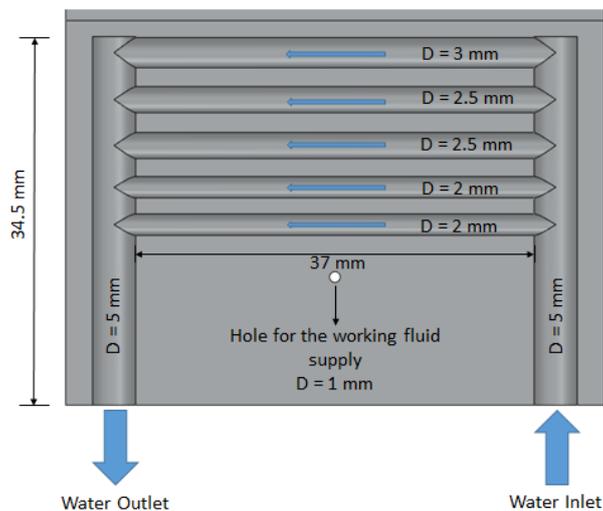

Figure 3. Cross section of the condenser section.

The thermal circuit is showed in Fig. 4. It represents the heat transfer between the evaporator and the condenser. With the temperatures obtained in the experimental analysis, the equivalent thermal resistance and the effective thermal conductivity of the MHP array could be calculated. The equivalent thermal resistance was calculated considering all of the thermal resistances presented in Fig. 4, while the effective thermal conductivity was calculated considering only the brass wafer with the microchannels. The subscripts presented are the initials of each materials name. The subscript "vert" means a thermal resistance in the vertical direction. The subscripts "BET. CHANNELS" and "AFTER CHANNELS" mean the material between each microchannel and the material after all of the microchannels, respectively, that also transfer heat by conduction.
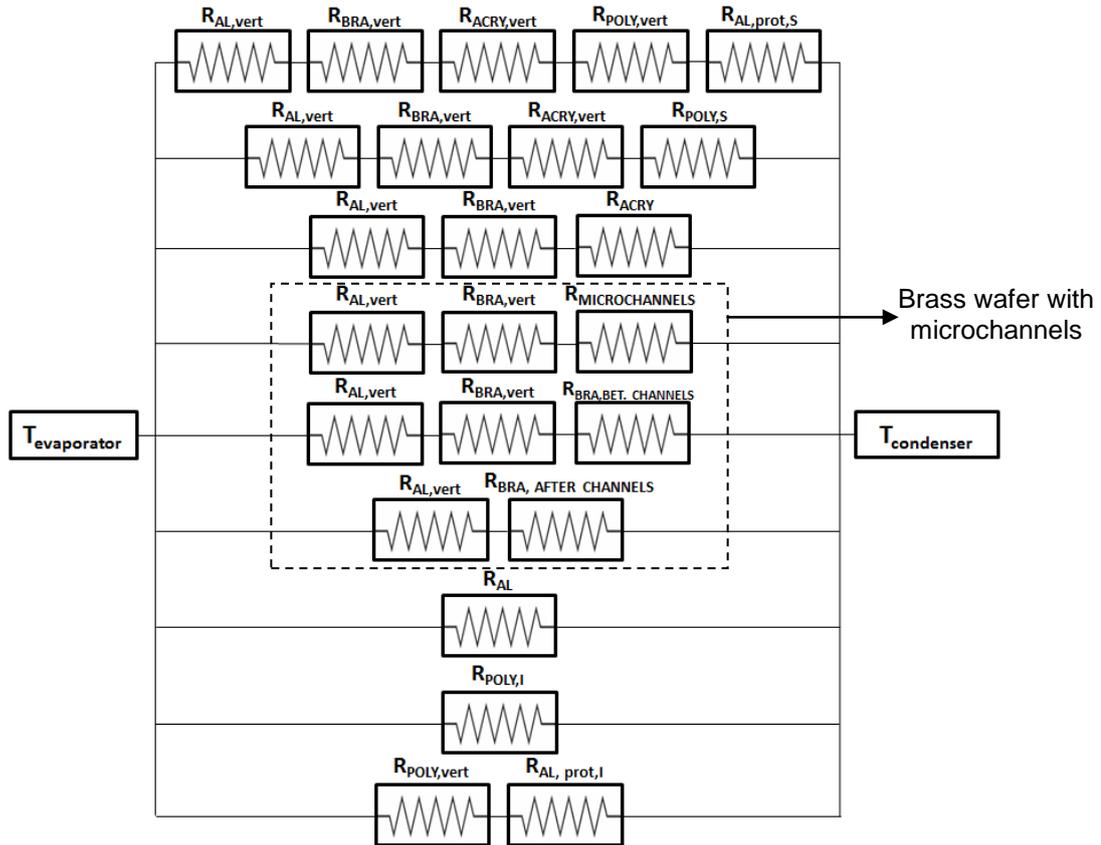
Figure 4. Thermal circuit between the evaporator and the condenser.

Figure 5 shows the relation between the equivalent thermal resistance (R_{eq}) and the thermal conductivity of each microchannel ($K_{microchannel}$), obtained by the thermal circuit model. The calculated values are shown in Table 1.
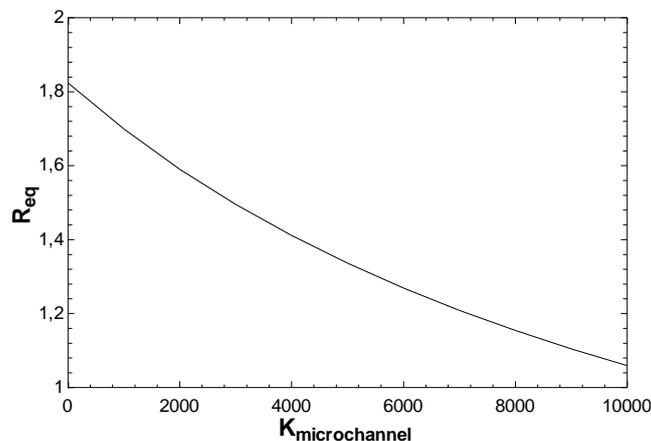
Figure 5. Equivalent thermal resistance of the system as a function of the thermal conductivity of each microchannel.

Table 1. Theoretical results obtained by the thermal circuit model.

$K_{microchannel}$ (W/m·°C)	R_{eq} (°C/W)
0	1.82
1000	1.69
2000	1.59
3000	1.49
4000	1.41
5000	1.33
6000	1.26
7000	1.21
8000	1.15
9000	1.10
10000	1.06

3. RESULTS AND DISCUSSION

The temperatures of the MHP array were measured with type K thermocouples for two conditions of the microchannels in steady state: empty and filled with working fluid. The amount of working fluid was measured comparing the masses of the filled and empty assembly. The analyses were carried with the condenser above the evaporator. In this position, the gravity acts in favor of the capillary effect. The thermal load provided was about 7.9 W. Table 2 shows the temperatures obtained experimentally, the thermal resistance of the system (R_{eq}), the effective thermal conductivity of the brass wafer with the microchannels (K_{eff}) and the thermal conductivity of each microchannel calculate by the thermal circuit model for each filling ratio (0%, 56.4% and 71.9%). The filling ratio is the ratio between the volume of working fluid inside the MHP array and the internal volume of the array.

Table 2. Results for each condition.

Filling Ratio	$T_{evaporator}$ (°C)	$T_{condenser}$ (°C)	ΔT (°C)	R_{eq} (°C/W)	K_{eff} (W/m·°C)	$K_{microchannel}$ (W/m·°C)	$K_{eff,filled}/K_{eff,empty}$
Empty	23.30	6.30	17	2.15	105.65	-	-
56.4%	15	4.5	10.5	1.32	247.17	4954.9	2.26
71.9%	15.45	3.85	11.6	1.47	196.67	3174.4	1.86

The results presented an increase of 2.26 on the heat transport for 56.4% filling ratio. The evaporator temperature and the condenser temperature decreased 8.30 °C and 1.8 °C, respectively. The temperature difference between the evaporator and the condenser also decreased, by a factor of 2.33. When the filling ratio increased to 71.9%, the heat transport decreased. The possible reason was that the excess of working fluid flooded the array and impaired the movement of the fluid, which also prejudices the heat transport.

The thermal conductivity of the brass considered in these calculations was 109 W/(m·°C). The effective thermal conductivity of the empty MHP array is smaller than the thermal conductivity of the brass, because the empty microchannels transport much less heat, as the thermal conductivity is low. Therefore, the useful area for the heat transport is smaller than it would be if the microchannels were filled with material.

Figure 6 and Figure 7 were obtained by a high-speed camera with 1500 frames per second. In Figure 6 is possible to observe the formation of vapor bubbles in the evaporator section. Figure 7 represents the condenser section, in which the vapor bubbles gradually decrease in size as de condensation occurs.

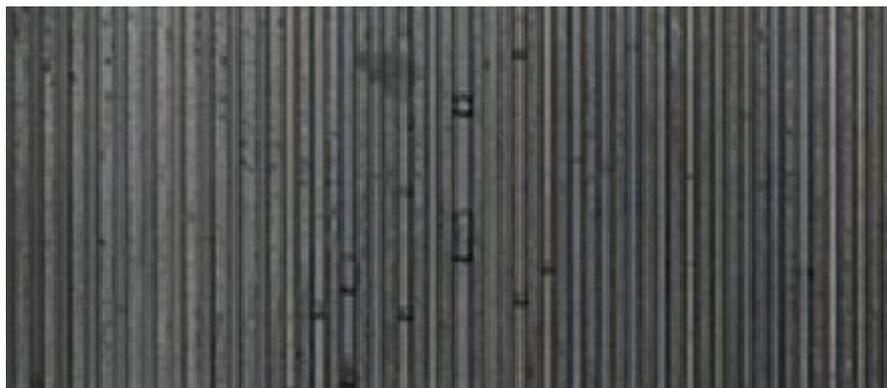Figure 6. Evaporator section of the MHP array.

Figure 7. Condenser section of the MHP array.

4. CONCLUSION

The micro heat pipe array studied in this work consisted of equilateral triangular grooves on brass wafer. The heat transport capacity of the array filled with working fluid revealed to be higher than the capacity of the brass itself. Applying the temperatures obtained with the experimental work on the thermal circuit model, an increasing factor of 2.26 for the effective thermal conductivity of the system was observed when the array was 56.4% filled with working fluid. As the amount of working fluid increased, the heat transport decreased, but still was higher than the empty array. The thermal conductivity of the microchannels increased from zero (empty) to 4954.9 W/(m·°C) for the best condition. As observed in this work and in previous works, the micro heat pipes showed to be thermally and dimensionally advantageous and the expansion of their use as a compact electronic cooling method is quite optimistic.

5. ACKNOWLEDGEMENTS

6. REFERENCES

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7. RESPONSIBILITY NOTICE