

Configurations of Phosphor Bronze Meshes in Heat Pipes: An Experimental Analysis of Thermal Performance

Larissa Krambeck¹, Felipe B. Nishida¹, Paulo H.D. Santos², Thiago Antonini Alves¹

¹Federal University of Technology – Paraná, 84.016-210, PONTA GROSSA, Brazil

²Federal University of Technology – Paraná, 80.230-901, CURITIBA, Brazil

Abstract— Heat pipes are used to improve the heat transfer in several products. It is known that metallic mesh configuration and size has influence on thermal performance of heat pipes. Thus, in this research, the thermal behavior of heat pipes with three different mesh configurations is experimentally analyzed. The heat pipes were manufactured using copper tubes with an outer diameter of 9.45 mm, an inner diameter of 6.35 mm, a length of 200 mm and phosphor bronze meshes as capillary structures (single layers of mesh #60 and #160, and two layers of mesh #60 and #160). The working fluid used was deionized water. The condenser was cooled by air forced convection, the adiabatic section was insulated by a fiberglass tape, and the evaporator was heated using a nickel-chromium alloy power metal strip resistors. The heat pipes were tested horizontally for increasing heat loads varying from 5 to 35W. The experimental results showed that the use of phosphor bronze meshes as the capillary structure proved to work successfully in all tested heat pipes; however according to the thermal resistances, the best results were observed for capillary structure composed by two layers of mesh (inner layer with mesh #160 and outer layer with mesh #60).

Keywords— experimental analysis, heat pipe, phosphor bronze mesh, thermal performance.

I. INTRODUCTION

Heat pipes are used to enhance the heat transfer in many different products. The heat transmitted through a heat pipe is based on phase change, consequently it can be pointed out that they can have thermal conductivities of 100-500 times of a solid metal rod with similar dimensions. Major advantages of heat pipes include a very high thermal conductance, no pumping power requirements, no moving parts, and relatively low pressure drops. Heat pipes can also be applied for heat recovery in a hot exhaust gas system, domestic use, industrial applications and in thermal management of electronic packaging. More details on the principle of the heat pipes can be found in [1-2].

The capillary structure of heat pipes can be made of screen meshes. It is known that metallic mesh configuration and size has influence on thermal performance of heat pipes and this is a complex issue [3]. Thus, in this research, three heat pipes with different configurations of phosphor bronze meshes, single layer of mesh #60, single layer of mesh #160, and two layers of mesh, were tested horizontally and compared in order to evaluate the best heat pipe thermal performance.

II. EXPERIMENTAL PROCEDURE

2.1 Description of the experimental device

The methodology for manufacture, test, and analyze the heat pipes was based on [4]. The heat pipes were produced by copper tubes with an outer diameter of 9.45 mm, an inner diameter of 6.35 mm, a length of 200 mm and phosphor bronze meshes as capillary structures (Fig. 1). The heat pipes have an evaporator region of 80 mm in length, an adiabatic region of 20 mm in length and a condensation region of 100 mm in length. The working fluid used was deionized water.



Fig 1. A copper heat pipe.

The mesh configurations analyzed in this research are shown in Fig. 2, comprising standard phosphor bronze meshes. The internal capillary structures of the heat pipes are: single layer of mesh #60 - Fig. 2(a), single layer of mesh #160 - Fig. 2(b), and two layers of mesh (inner layer with mesh #160 and outer layer with mesh #60) - Fig. 2(c).

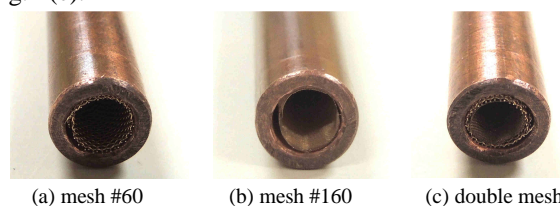
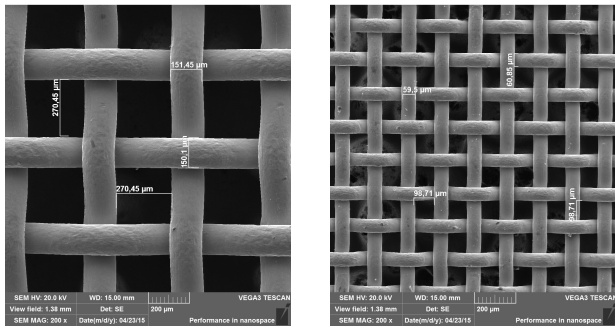


Fig. 2. Mesh configurations.

Figures 3(a) and 3(b) show micro-scale images of phosphor bronze meshes 60 and 160, respectively. The images were obtained by Backscattered Electron Detector (BSD) for Scanning Electron Microscope (SEM).



(a) mesh #60

(b) mesh #160

Fig 3. Micro-scale view of the capillary structure.

2.2 Filling station

The amount of working fluid inserted in the pipe is very important for capillary pumping system because the heat transfer depends on it. If there is not enough fluid, the pumping system stop working and the heat pipe collapses. As a result, the heat transfer is interrupted. Before the filling of the heat pipe with deionized water, it is necessary to make vacuum inside the copper tube (Fig. 4). During the vacuum process, the internal pressure reached 90 mbar (9 kPa) and the saturation temperature related to this pressure was about 43.74°C.



Fig. 4. The vacuum pump and the heat pipe.

Figure 5 shows the filling station of the heat pipe. At the moment of the filling, it is necessary to be very careful in order not to lose the existing vacuum inside the tube. If that occurs, the whole vacuum process should be repeated. Initially, the burette was filled with the required working fluid volume. Then, the burette valve and the forceps were carefully opened to drain the fluid through the hose until the pipes were loaded with 1.41 ml, 1.35 ml, and 1.34 ml, respectively for single layer of mesh #60, single layer of mesh #160 and two layers of mesh (double mesh).

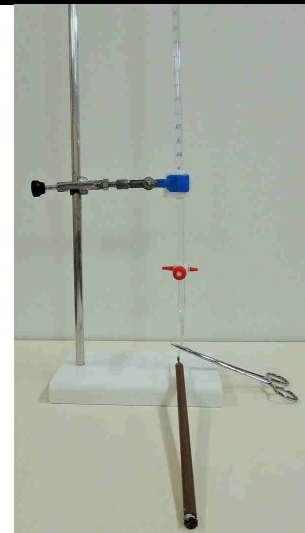


Figure 5. Filling station for the heat pipe.

2.3 Description of test rig

The heat pipe was heated using a power supply unit (Politerm™ POL 16B), which applied a potential difference around the evaporator using a nickel-chromium alloy power strip resistor (heating system). A fiberglass tape was used on the adiabatic section as a thermal insulator and the cooling system consists of an equipment to make air forced convection on the condenser region, as shown in Fig. 6.

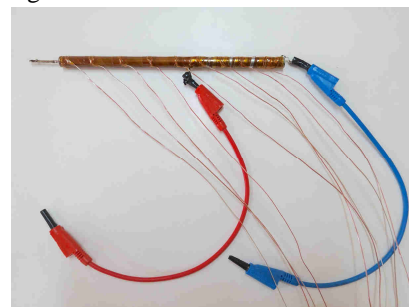


Fig 6. View of the heat pipe, showing the heating system.

The heat pipe temperatures were measured using K-type thermocouples (Omega™) and a data acquisition system: data logger (Agilent™ 34970A with 20 channels) and a Dell™ desktop. Thermocouples were attached to the external surface of the evaporator, of the adiabatic section and of the condenser, as shown in Fig. 7.

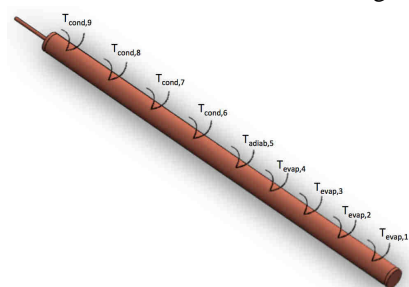


Fig 7. Positions of the thermocouples.

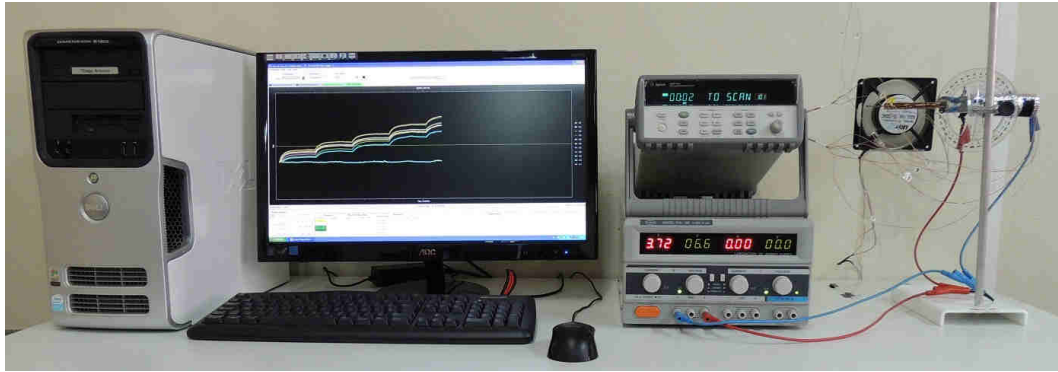


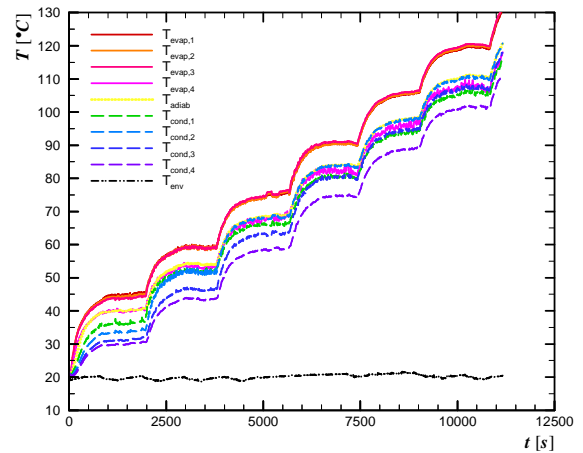
Fig. 8. General view of the test rig.

Figure 8 shows the experimental test rig used for testing the heat pipe at horizontal position.

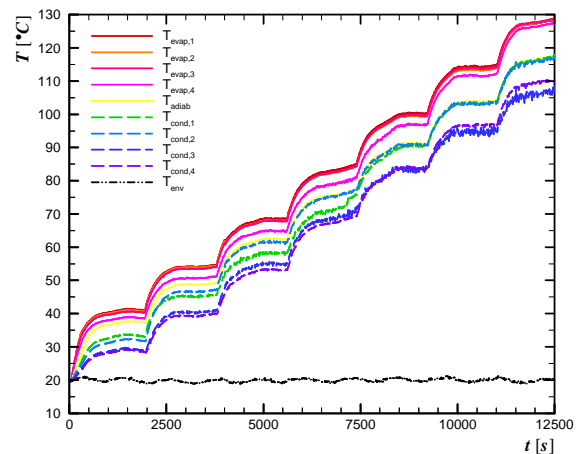
III. EXPERIMENTAL RESULTS

The experimental results regarding thermal performance of the heat pipes using three different mesh configurations are presented. The tests were repeated three times for each mesh configuration and the comparative errors taking into account the mean values were lower than 0.5°C. Tests were performed for increasing heat loads varying from 5W up to 35W. The ambient temperature was kept at 20.0 ± 0.5°C by air-conditioning system. For security reasons, the tests were immediately stopped when the highest temperature along the heat pipe reached 125°C. The experimental uncertainties of the temperature were estimated in approximately ± 1.0°C and heat load were ± 1%.

Figure 9 shows the heat pipes temperatures for different heat loads for: (a) mesh #60, (b) mesh #160, and (c) double mesh. For each heat load applied, it is observed a tendency of the temperatures stabilize. To mesh #60 and mesh #160, the tests were interrupted when a heat load of 35W was applied because the evaporator temperatures reached the security temperature. However, heat pipe with the double mesh worked successfully up to 35W.



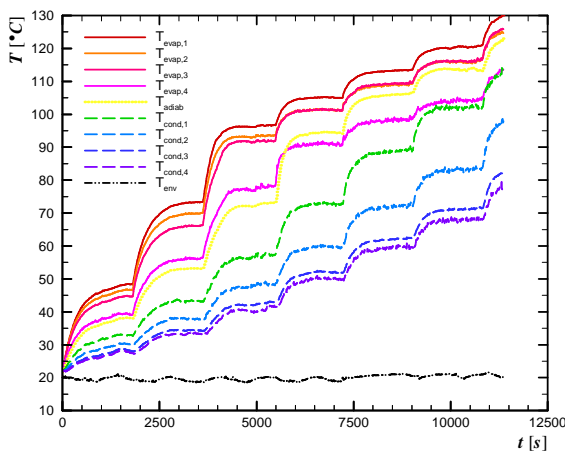
(b) mesh #160



(c) double mesh

Fig. 9. Temperatures of the heat pipe versus time for different heat loads.

Figure 10 shows the thermal resistances of the heat pipes due to different heat loads. It can be observed that the behavior heat pipe with mesh #160 was the worst. On the other hand, the results for mesh #60 and double mesh were similar, however the double mesh presented the best results.



(a) mesh #60

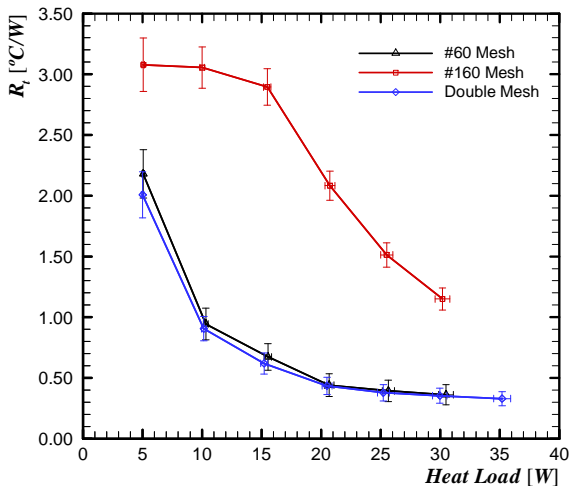


Fig. 10. Heat pipes thermal resistances versus heat load.

IV. CONCLUSIONS

This paper presents an experimental study of three copper heat pipes with different configurations of phosphor bronze meshes as capillary structures. These mesh configurations were: single layer of mesh #60, single layer of mesh #160 and two layers of mesh (inner mesh #160 and outer layer mesh 360). The heat pipes were tested horizontally with deionized water. The experimental results showed that for all configurations the heat pipes worked successfully. The heat pipes with single layer of mesh #60 and single layer of mesh #160 worked until 30W and the heat pipe with two layers of mesh (double mesh) worked until 35W. Thus, the heat pipe with double mesh was the best and presented, moreover, the best thermal resistances.

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