The Impact of Orientation on a Heat Pipe's

Performance with Different Wick Structures

Introduction

The thermal performance of a heat pipe depends strongly on its orientation in operation relative to gravity. For a specific orientation, this performance is determined by the wick structure present inside the heat pipe. Wick structures exhibiting low capillary pressure perform best in gravity-assisted applications, where the evaporator is located below the condenser. However, a wick structure producing high capillary pressure will be needed if a heat pipe is to be operated in a gravity adverse orientation. A previous Qpedia article detailed how a heat pipe's performance is really dependent on both orientation and wick structure [1]. This article builds on that same topic, as it presents a review of experimental results obtained with heat pipes, in the shape of round cross sections, in different orientations [2], [3]. The results are compared with data published in the literature [4], [5].

Experimental Setups

A first set of experiments was conducted in order to assess the thermal performance of several heat pipes designed with round cross sections, under different orientations and heat loads [2]. The orientation angle was varied between -90° (evaporator vertically above the condenser) to 90° (condenser vertically above the evaporator). Heat pipes fitted with three types of wick structures were investigated: grooved, mesh, and sintered metal powder.

The experimental study was divided into two parts. The first part evaluated the thermal performance of heat pipes with three (3) outer diameters (OD) (4, 5 and 6 mm), for different inclination angles, at a fixed heat load. In the second part, the thermal performance of a fixed geometry (6mm OD, 200 mm length) and fixed wick (sintered powder metal) heat pipe, for different inclination angles, at three (3) operating temperatures (35, 45 and 55 °C), was measured.

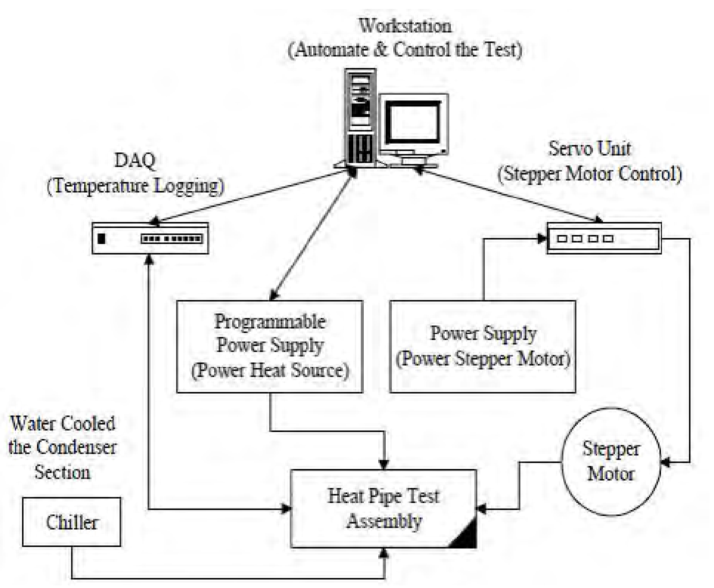

Figure 1. Schematic of Test Setup [2]

The heat pipes were tested in the setup presented schematically in Figure 1. The entire test cycle is automated, controlled by a computer. The servo unit controls a stepper motor which tunes the inclination angle. The condenser section is cooled with the help of a refrigerated circulating bath. The purpose of the chiller is to maintain the condenser blocks at a constant temperature throughout the testing process.

The actual test setup is shown in Figure 2. The test assembly was designed to fit heat pipes of different diameters and lengths. The heat pipe test sample is placed in the center groove between two copper blocks, held together by screws. The dimensions of the copper blocks are 55W x 55L x 8H mm. The copper blocks are mounted on the insulator blocks using screws. A 40 x 40 mm TEC serves as the heat source. The heat source sits in a square cut out on the Phenolic insulator block.

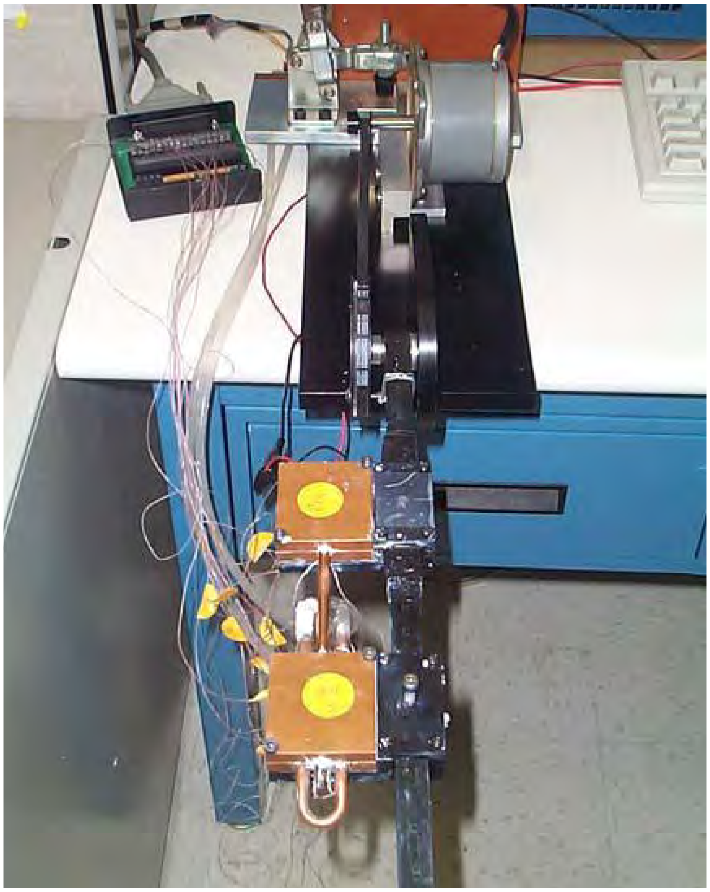

Figure 2. Test Setup Used in the Experiment 1 [2]

On the evaporator side, the bottom copper block is directly mounted on the heat source. On the condenser side, the bottom copper block is fitted with copper tubing to re-circulate water from the blocks to the chiller. The water inlet temperature of the block is maintained by the refrigerated circulating bath. Thermal grease is applied to the interface between the heat source and the copper block, and between the copper blocks and the heat pipe. A total of fourteen (14) T-type thermocouples are used in this test rig. Two thermocouples are inserted into the PVC tubing to monitor the water inlet temperature and the water outlet temperature, and six (6) thermocouples on evaporator blocks and condenser blocks are used to measure the block temperature and the interface temperature between the block and the heat pipe. The locations of the thermocouples placement within the copper blocks are shown in Figure 3.

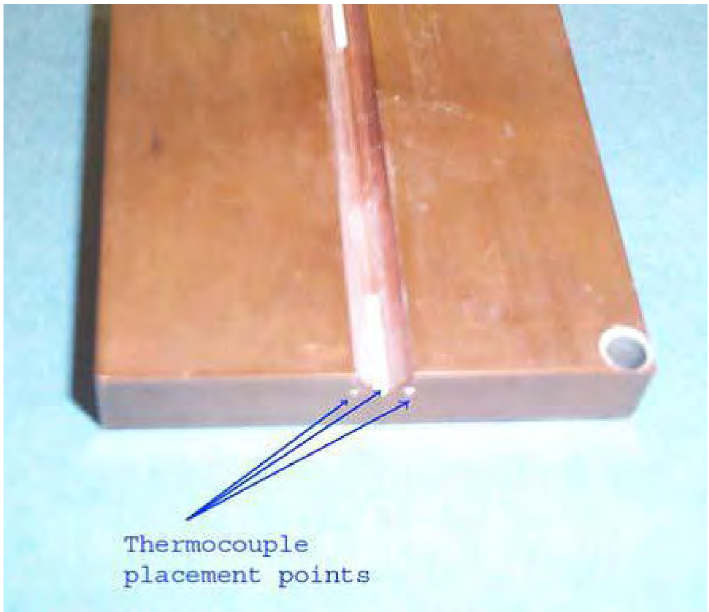

Figure 3. Thermocouples Location on the Evaporator and Condenser Blocks [2]

There are a total of 3 different sets of evaporator and condenser blocks with groove diameters of 4, 5, and 6mm designed to accommodate different heat pipe diameters. Table 1 lists the test samples dimensions and the test configuration.

# of Test Samples	3	3	3
Evaporator Length (mm)	55	55	55
Condenser Length (mm)	55	55	55
Test Length (mm)	200	200	200
Outer Diameter (mm)	6	5	4
Wick Structures	Groove Mesh Metal Powder	Groove Mesh Metal Powder	Groove Mesh Metal Powder

Table 1. Details for the Orientation Study

A second set of experiments was conducted in order to assess the thermal performance of a 6.35 mm outer diameter, 300 mm long copper heat pipe under different orientation angles [3]. The heat pipe had sintered copper powder as the wick and used water as the working fluid. The test setup used is shown in Figure 4.

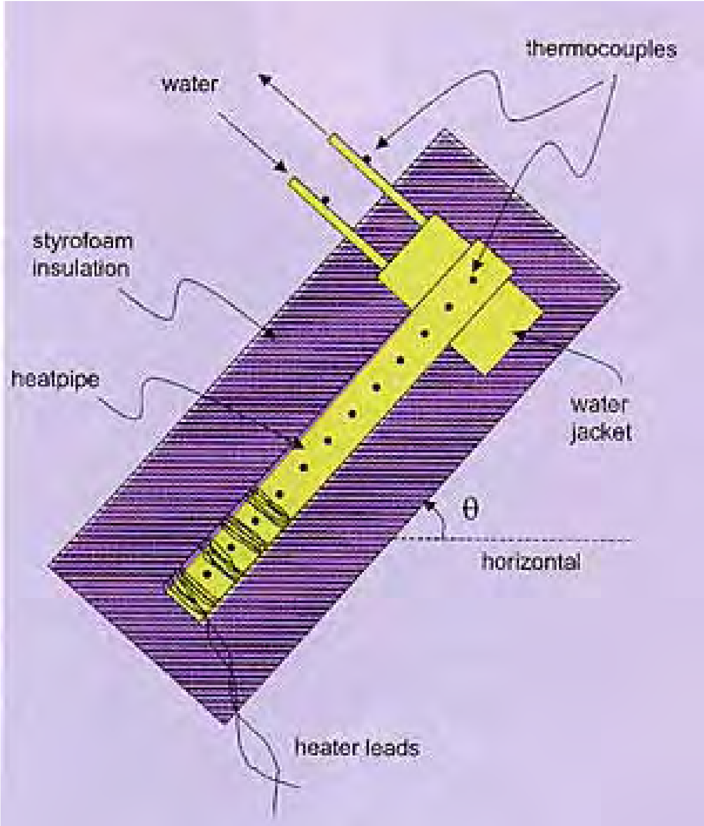

Figure 4. Test Setup Used in the Experiment 2 [3]

14 Type E thermocouples were attached with epoxy at equally spaced intervals in order to measure the temperature profile along the heat pipe. The evaporator section was defined by winding and epoxying heater wire on a 75 mm long section at one end of the heat pipe. A condensing portion was formed at the other end by a 75 mm long water jacket consisting of copper tubing placed around the heat pipe. The complete apparatus was encased in a block of Styrofoam for thermal insulation. Also, the apparatus shown in Figure 4 was mounted on a rotatable support to allow operation at angles from - 90° to +90°.

Test Procedure

For the first part of the experiment, each test started at +90°, the vertical position where the evaporator is located vertically below the condenser. The test ran through a 180° sweep that paused at each of the following inclination angles: +60°, +30°, 0° (horizontal), -30°, -60° and –90° (the evaporator located vertically above the condenser). An initial heat load of 10 Watts (for 6mm and 5mm OD heat pipes) and 5 Watts (4mm OD) was applied to the evaporator respectively. After steady state was reached at each inclination angle, the program instructed the power supply to increase the heat load in an incremental step of 5 W. This procedure is repeated until the specified cut-off evaporator temperature is reached. When that occurs, the program instructs the stepper motor to lower the heat pipe test setup to the next specified inclination angle. This procedure continues until the heat pipe is tested at all specified angles.

For the second part of the experiment [3], the inlet water temperature was adjusted at each power level to maintain roughly constant temperature at the cool end of the heat pipe. At each power level, average temperatures were defined for the evaporator section (first three thermocouples) and the condenser section (last three thermocouples).

Test Results

The results are presented as plots of temperature differential (interface to interface) or maximum power against angle of inclination. The temperature differential is defined as the difference in temperature between the evaporator and the condenser. The evaporator and condenser temperatures are measured at the center groove of the copper blocks (shown in Figure 3) that interface with the heat pipe test sample.

For the first experiment, the first set of results is presented in Figures 5, 6 and 7. They show the heat pipe's performance at constant heat input for different inclination angles. The heat input was 10 W for 5 and 6 mm OD heat pipes and 5 W for 4 mm OD heat pipe. All the heat pipes tested were 200 mm long.

As illustrated in the graphs, the sintered powder metal wick heat pipe is the least impacted by orientation. For the 6 mm OD heat pipes, the grooved heat pipe performed best at inclination angles in the range 0° to +90°. However, for the 5 mm OD heat pipes, grooved and sintered powder metal wick heat pipes performed similarly from 0° to +90°. Further decreases in OD (4 mm) results in almost equal performance for the three types of heat pipes tested, for inclination angles ranging from +30° to +90°.

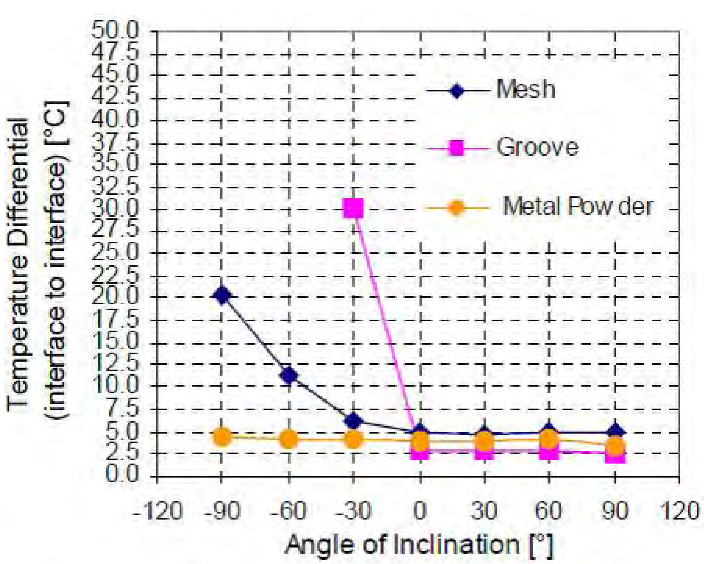

Figure 5. Thermal Performance of 6 mm OD, 200 mm Length Heat Pipes at Different Inclination Angles, for Heat Load 10 W [2]

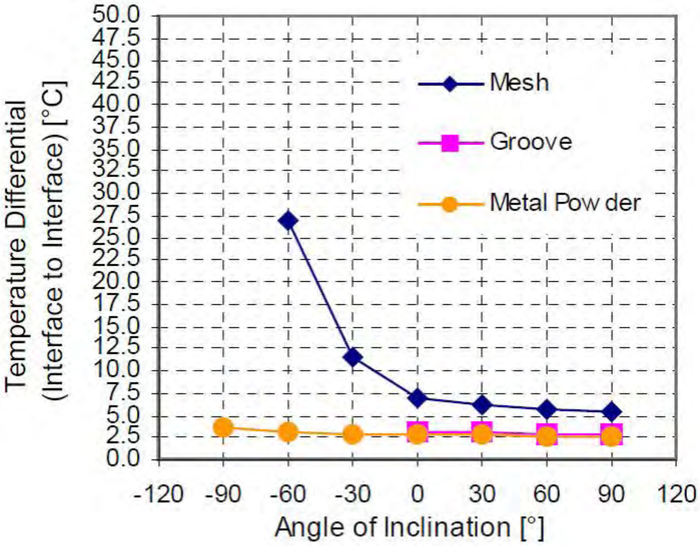

Figure 6. Thermal Performance of 5 mm OD, 200 mm Length Heat Pipes at Different Inclination Angles, for Heat Load 10 W [2]

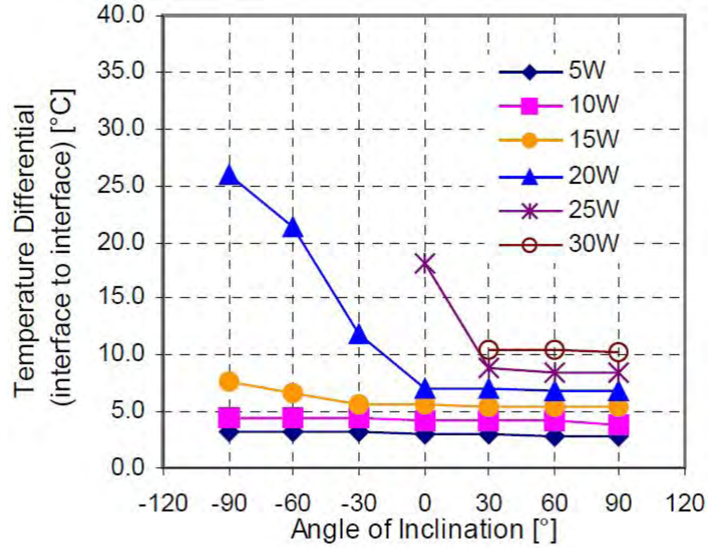

Figure 8. Thermal Performance of a 6 mm OD, 200 mm Length Sintered Powder Metal Heat Pipe at Different Inclination Angles, for 35 °C Operating Temperature [2]

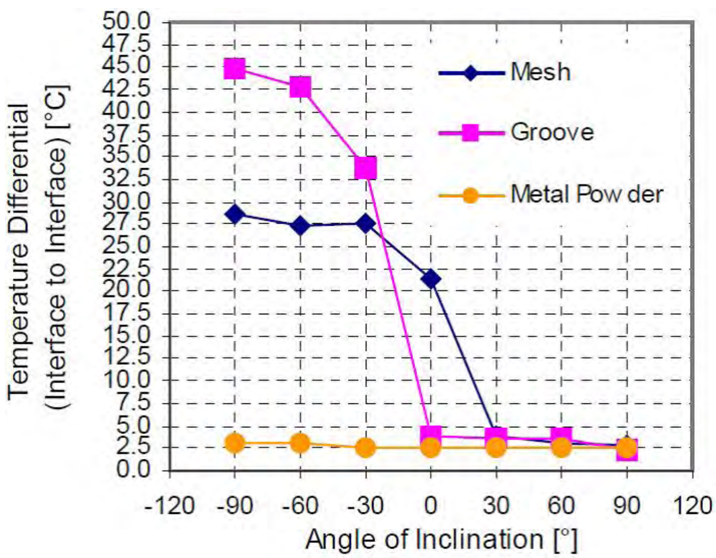

Figure 7. Thermal Performance of 4 mm OD, 200 mm Length Heat Pipes at Different Inclination Angles, for Heat Load 5 W [2]

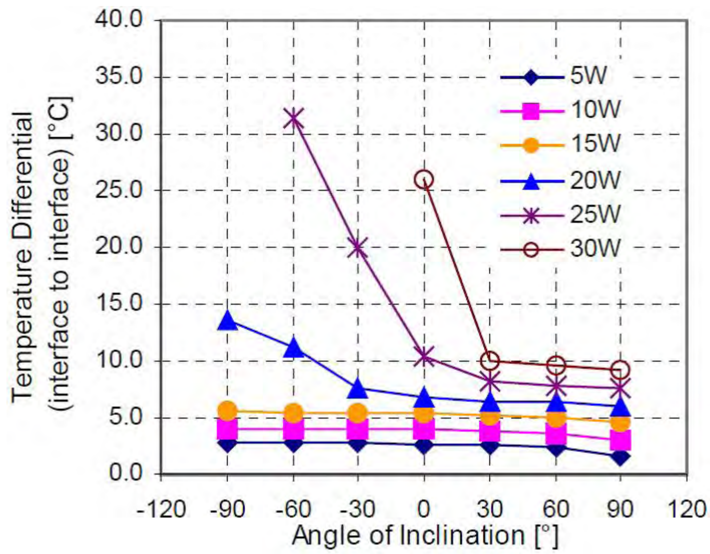

Figure 9. Thermal Performance of a 6 mm OD, 200 mm Length Sintered Powder Metal Heat Pipe at Different Inclination Angles, for 45 °C Operating Temperature [2]

The second part of the experimental investigation aimed at measuring the thermal performance of a 6mm OD, sintered metal powder wick heat pipe under different operating temperatures and inclination angles.

The working temperatures tested were 35, 45 and 55 °C. The results are presented in Figures 8, 9 and 10, respectively. As a general observation, heat pipe thermal performance increases with higher operating temperature.

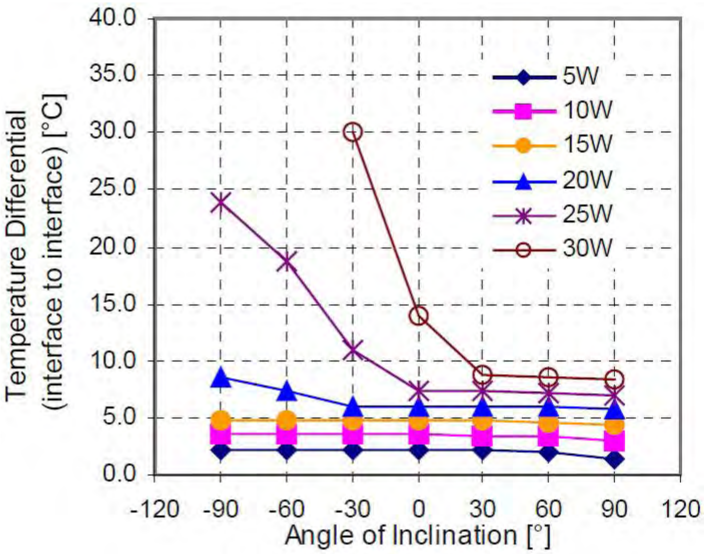

Figure 10. Thermal Performance of a 6 mm OD, 200 mm Length Sintered Powder Metal Heat Pipe at Different Inclination Angles, for 55 °C Operating Temperature [2]

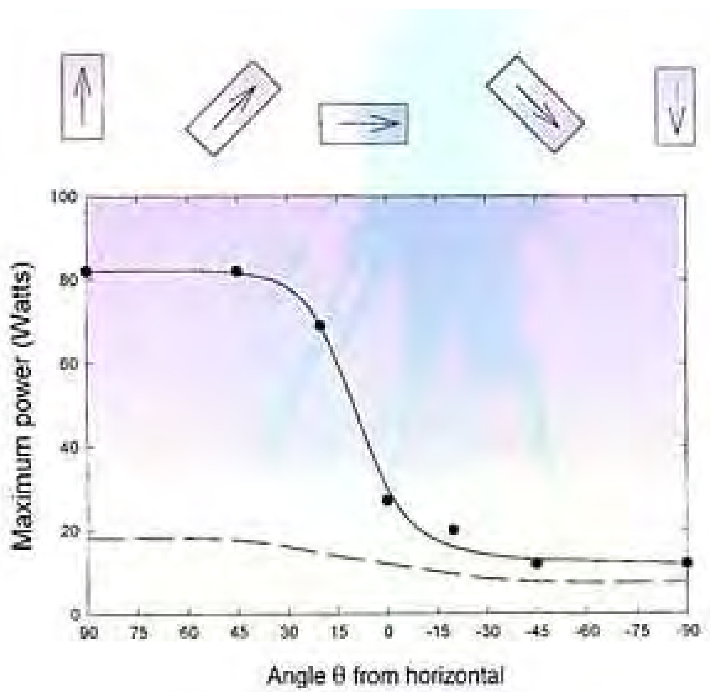

Figure 11. Thermal Performance of a 6.35 mm OD, 300 mm Length Sintered Copper Powder Wick Heat Pipe at Different Inclination Angles, for 95 °C Operating Temperature [3]

Sample results from the second set of experiments are shown in Figure 11. The graph illustrates the dependence of the maximum stable heat-carrying capacity on angle of inclination for an average temperature of 95°C. The arrows above the graph indicate the heat flow direction, while the dashed line represents the manufacturer's recommended maximum heat. The maximum power is clearly highest when the condensed working fluid is returned to the evaporator with the help of gravity. The manufacturer's recommended maximum power is found to be conservative for this particular heat pipe.

Conclusions

Several round heat pipes with three types of wick structures were tested for thermal performance under different inclination angles, heat loads and operating temperature conditions. The three wick types were: groove, mesh and sintered metal powder.

The results showed that the heat pipes fitted with a sintered metal power wick performed better in the gravity opposed orientations (inclination angles from -90° to 0°). This is due to the higher capillary pressure exhibited by this type of wick structure. So, for applications where the evaporator has to be placed above the condenser, they are the preferred choice.

Another conclusion of the experimental study is that for a 6mm OD, the grooved heat pipe has better thermal performance than mesh and sintered powder metal in the 0° to +90° inclination angle range. Also, the maximum heat that a heat pipe can transport depends strongly on the heat pipe orientation. As expected, thermal performance improved with increased operating temperature, similar to results reported in literature [4], [5].

The results of the experimental study are very useful, offering insight into thermal performance being dependent upon factors such as inclination angle, heat input and operating temperature. However, the results have to be expanded to a broader range of geometrical parameters (OD, length) to gain generality, as current conclusions are drawn based on one OD and one length (200 mm). Also, it will be useful to test flat heat pipes, since these are widely used in electronics cooling applications.

References:

1. **Advanced Thermal Solutions, Inc., Qpedia eMagazine,"How Wicks and Orientation Affect Heat Pipe Performance", August 2009.**

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