Comparative Study of Heat Pipes Performances in Different Orientations

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Abstract

The orientation of a heat pipe plays an important role in its performance. The performance of a heat pipe under specific orientations is directly related to its wick structure. Wick structures with low capillary limit work best under gravity-assisted conditions, where the evaporator is located below the condenser. There are numerous published studies that explore heat pipe performance limits, however none of them explicitly looked into the effect of orientation on heat pipe performance with different wick structures. The objective of this paper is to conduct a comparative study on heat pipe performance with different wick structures subjected to different orientations. The published results maybe serve as a reference for mechanical and electrical engineers when they try to incorporate heat pipes into their thermal solutions.

Keywords

Heat pipe, wick structures, gravity-assisted, angles of orientation

1. Introduction

The performance of the heat pipe depends on numerous factors. Heat pipe diameter and length (particularly the adiabatic length) are one of the factors determining how much heat the pipe can transfer. However, other factors are equally important. A heat pipe performance ultimately depends on the application (i.e. how and where the heat pipe is used). The heat pipe flattening and or bending, ambient temperature as well as the orientation of the heat pipe will influence its performance.

This paper investigates the influence on the performance of the heat pipes with the changes in the orientation angle from –90° to +90°. The paper investigates three heat pipe wick structures and their performance with the changes in the orientation.

First, the paper examines and compares the performance of different wick heat pipes at various inclination angels at fixed heat load. The results are presented for 3 different diameter heat pipes.

Second, a performance of the three different wick heat pipe was examined at increasing power intensity at different inclination angles. The results are presented for 6mm diameter pipes.

Finally, the performance of a 6mm diameter, sintered powder metal heat pipe was examined with the changes in the ambient temperature as well as the inclination angle. The results are presented for ambient temperatures of 35, 45 and 55°C.

1.1. Previous Works

Sauciuc (2000) studied the heat pipe performance with different wick structures under increasing heat load at gravity-assisted orientation.

Reid and Merrigan (1997) at Los Alamos National Laboratory conducted a literary survey reviewing the heat pipe activity in this country dating from 1990 to 1995. In the Heat Pipe Performance Limit section, they found a number of technical papers and books performed experimental studies on the 4 major limitations of heat pipe – capillary, boiling, entrainment and transport limit.

Shimura (2002) investigated the heat pipe thermal resistance with different working fluids at various inclination angles in gravity-assisted condition.

2. Experimental Setup

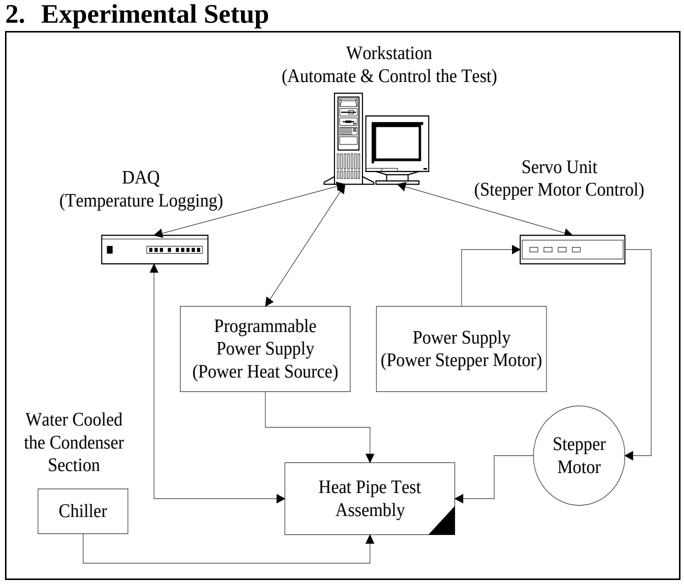

Figure 1. Test Setup Schematic

Figure 1 shows the schematic of the test setup. The entire test cycle is controlled and automated by computer. The DAQ and terminal block are used for temperature logging. The programmable power supply communicates with the computer through GPIB interface to control the heat load, and the servo unit controls the stepper motor for inclination angles tuning. The refrigerated circulating bath provides cooling to the condenser section of the test assembly. The main purpose of the chiller is to maintain a constant cooling temperature at the condenser blocks throughout the heat pipe testing process.

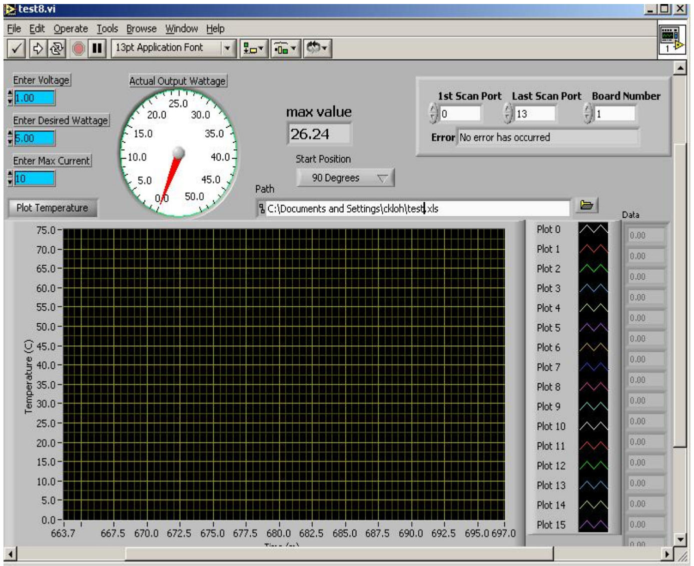

Figure 2. Test Control Interface

The program controls for DAQ and Servo Unit were coded in LabVIEW™ graphical language. Figure 2 displays the program interface for heat pipe testing. The program allowed us to input the initial stepping voltage, the maximum heat load in Watts, and the maximum current setting. In addition, the program also managed the programmable power supply such that the heat load is always maintained at ± 5% of its input value.

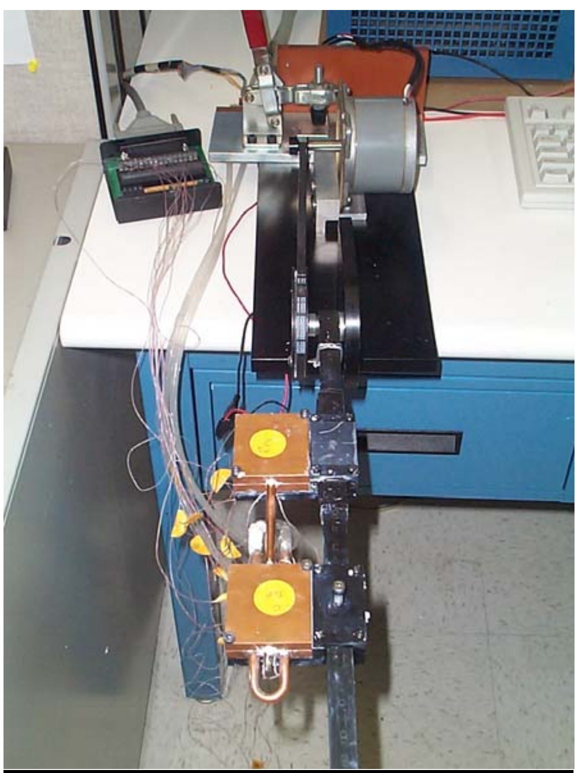
Figure 3. Heat pipe experimental setup.

Figure 3 depicts the heat pipe performance test setup. 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 the copper blocks, held together by screws. The dimensions of the copper blocks are 55W x 55L x 8H mm. On the evaporator side, the bottom copper block is directly mounted on the heat source (40 x 40 mm TEC). The heat source sits in a square cut out on the Phenolic insulator block. The copper blocks are mounted on the insulator blocks using screws. 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 T-type thermocouples are used in this testing. Two thermocouples are inserted into the PVC tubing to monitor the water inlet temperature and the water outlet temperature, and 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 4.

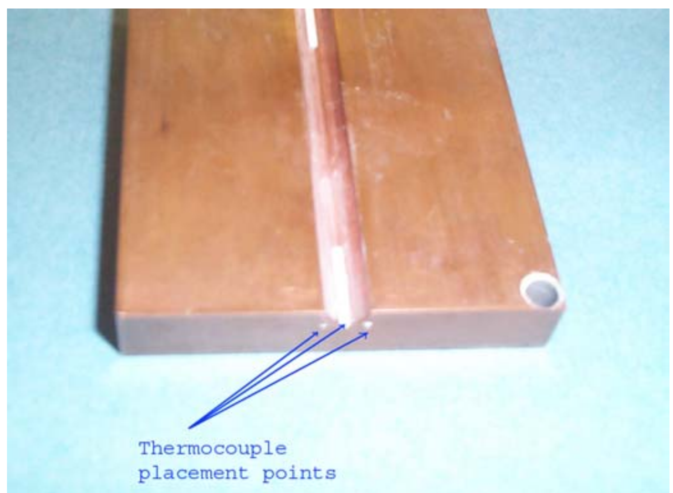

Figure 4. Thermocouples location on the evaporator and condenser block.

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

Table 1. Test samples configuration.

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

3. Test Procedure

Each test started at +90°, the vertical position where the evaporator blocks were located at the bottom and the condenser blocks were located on the top. The test run through a 180° sweep that paused at each of the following inclination angle: +60°, +30°, 0° (horizontal), -30°, -60° and –90° (the evaporator blocks were on top position and the condenser blocks were at the bottom). Initial heat load of 10 Watts (6mm and 5mm OD) and 5 Watts (4mm OD) were applied to the evaporator blocks respectively. When the test at each inclination angle reached steady state for a specified time period, the program instructed the power supply to increase the heat load in an incremental step of 5 Watts. This process is repeated until the specified cut-off evaporator temperature is reached. When that happened, the program instructed the stepper motor to lower the heat pipe test setup to the next specified inclination angle. This process is repeated until the heat pipe is tested at all specified angles.

4. Test Results

All the charts presented in this section are plotted as Temperature Differential (interface to interface) against Angle of Inclination. The Temperature Differential is defined as the difference in interface temperatures between the evaporator and the condenser. The interface temperature is the temperature measured at the center groove of the copper block (shown in Figure 4) that interfaces with the heat pipe test sample.

4.1. Different Wick Structures

Figures 5, 6 and 7 show the different wick structure heat pipes thermal performance at various inclination angles. The indicated test results are for 6mm, 5mm and 4mm Outer Diameter, 200mm long heat pipes. The heat load of 10W was applied to 6mm and 5mm OD heat pipes and 5W to 4mm OD heat pipe.

As illustrated in the Figures, orientation has less impact on the sintered powder metal heat pipe compared to the groove and mesh heat pipes. For 6mm OD, the groove heat pipe has the best performance from +90° to 0° (horizontal position) followed by sintered metal powder and mesh.. However, for 5mm heat pipe, the groove wick and sintered metal powder wick thermal performance were similar from +90° to 0° (horizontal position). At 5 Watts, the 4mm OD mesh, groove and sintered powder metal heat pipes performances were almost equal from +90° to +30°.

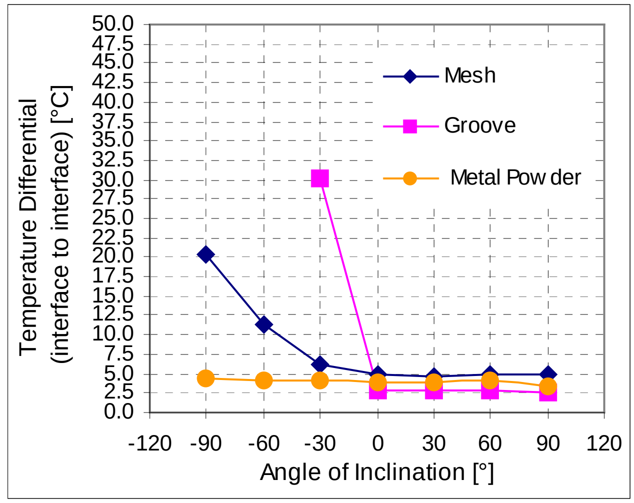

Figure 5. Thermal performance of 6mm OD, 200mm Length heat pipes with different wick structures at different inclination angles. Heat load of 10 Watts.

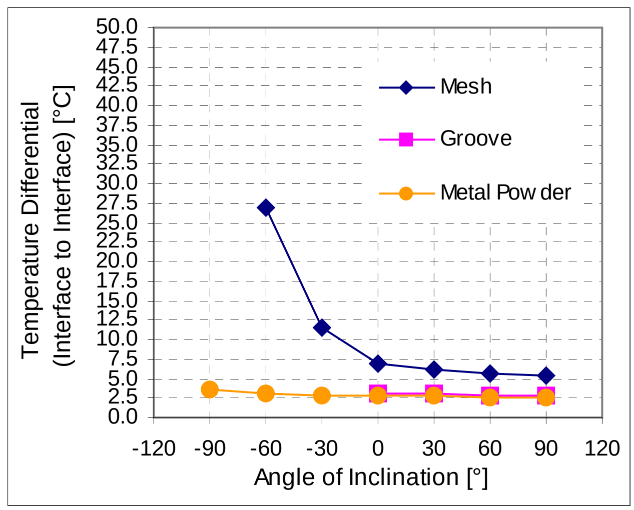

Figure 6. Thermal performance of 5mm OD, 200mm Length heat pipes with different wick structures at different inclination angles. Heat load of 10 Watts.

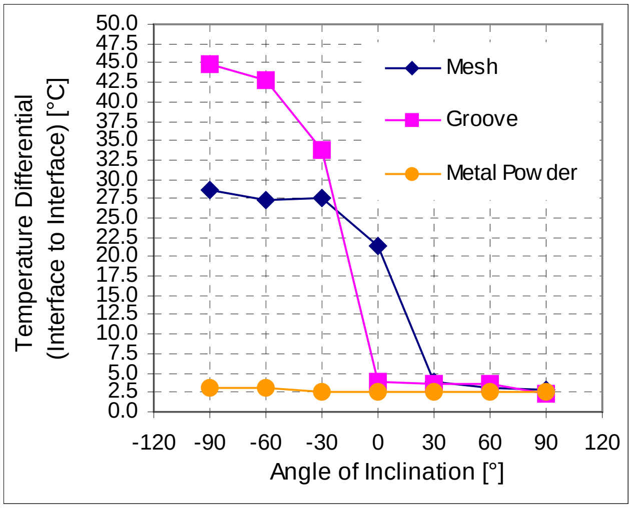

Figure 7. Thermal performance of 4mm OD, 200mm Length heat pipes with different wick structures at different inclination angles. Heat load of 5 Watts.

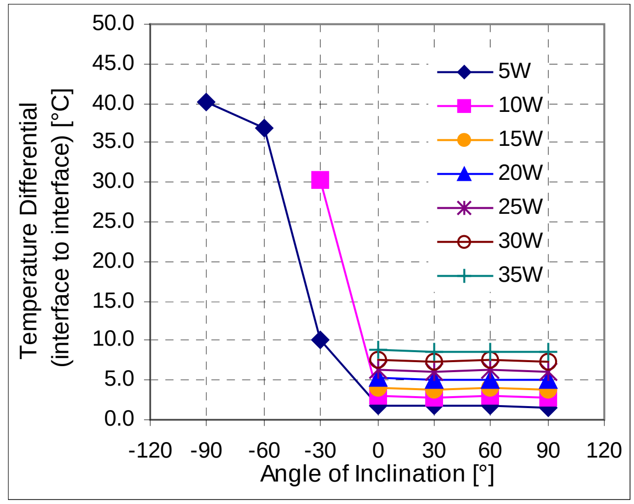

Figure 9. ΔT_{int} of 6mm OD, 200mm of groove heat pipe at different inclination angles.

4.2. Increase in Power Intensity

Figures 8, 9 and 10 show the temperature differential between the evaporator and condenser as the heat load increases for different wick structures. It can be seen that between +90° and +30°, there are slight variations between the temperature difference from the evaporator s to the condenser as the power increases. At power range of 5W to 10W, the temperature differential across the evaporator section and condenser section for metal powder wick structure remain flat throughout the 180° sweep. As presented in the charts, the groove heat pipe is the best heat transporter closely followed by mesh and metal powder wick structures at inclination angles ranging from +90° to 0° (i.e. gravity assisted to horizontal orientation) However, the sintered powder metal heat pipe performs significantly better in the gravity opposed orientations (inclination angles from 0 to –90)

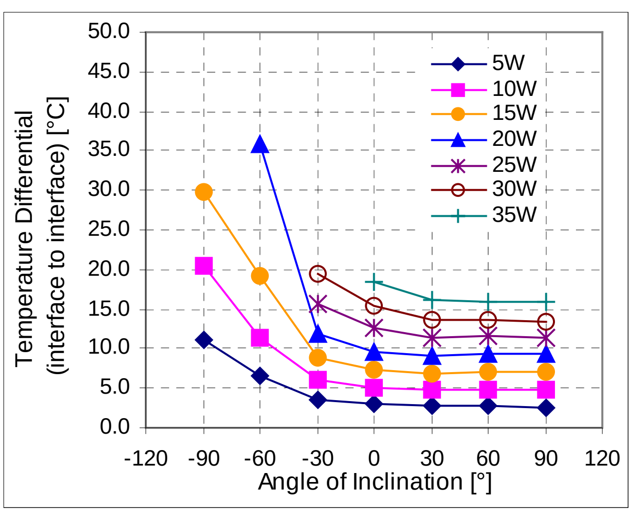

Figure 8. ΔT_{int} of 6mm OD, 200mm of mesh heat pipe at different inclination angles.

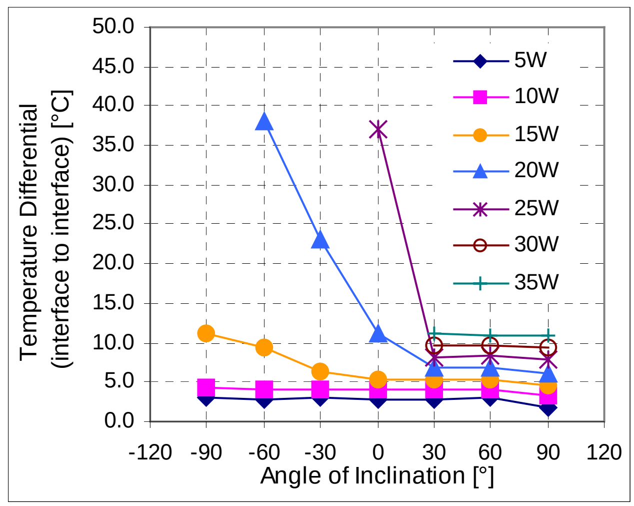

Figure 10. ΔT_{int} of 6mm OD, 200mm of metal powder heat pipe at different inclination angles.

4.2. Increase in Ambient Temperature

Figures 11, 12 and 13 show the temperature differential from evaporator to condenser at ambient temperature of 35°C, 45°C and 55°C for the metal powder wick structure heat pipe. It can be seen that as the ambient temperature increases, the temperature differential between the evaporator and condenser decreases. This suggests that the heat pipe is more efficient in heat transport at higher ambient temperature. As shown in the figures, the rise in ambient temperature significantly affects the heat transport capability at higher heat loads.

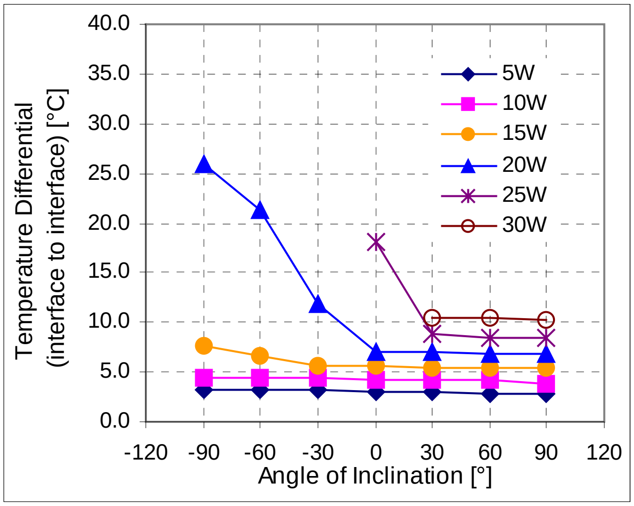

Figure 11. ΔT_{int} of 6mm OD, 200mm of metal powder heat pipe at ambient of 35°C for different inclination angles.

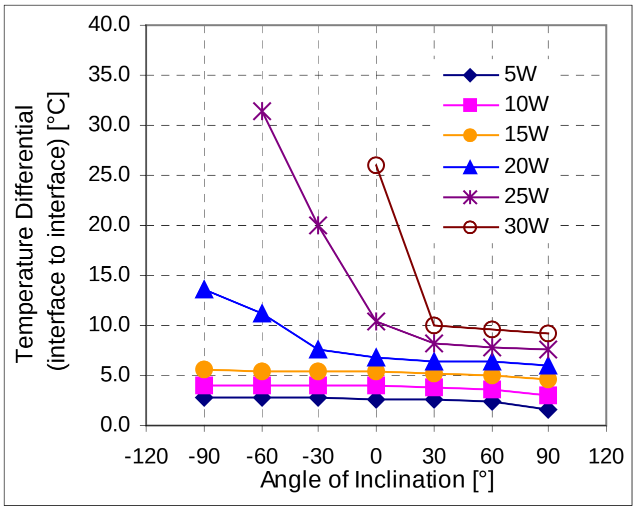

Figure 12. ΔT_{int} of 6mm OD, 200mm of metal powder heat pipe at ambient of 45°C for different inclination angles.

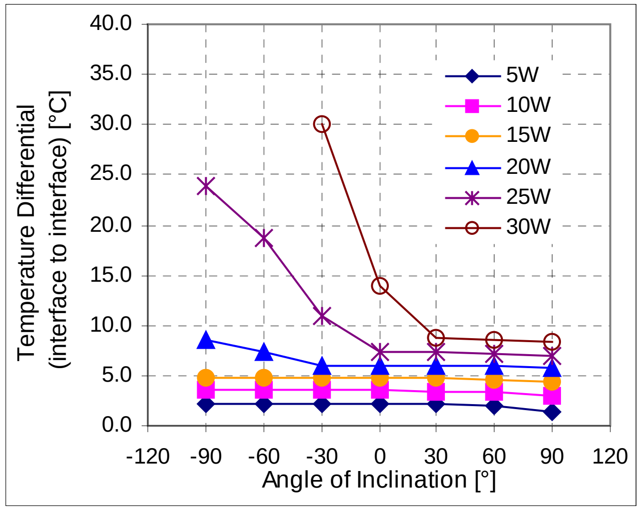

Figure 13. ΔT_{int} of 6mm OD, 200mm of metal powder heat pipe at ambient of 55°C for different inclination angles.

5. Conclusions

The heat pipes orientation test produced the following:

- Heat source orientation and gravity have less effect on sintered powder metal heat pipes due to the fact that the sintered powder metal wick has the strongest capillary action
- It is not desirable to use groove or mesh heat pipes when the orientation of the evaporator (heat source) is on top of the condenser (heat sink)
- For 6mm OD, the groove heat pipe has better thermal performance that mesh and sintered powder metal in the +90° to 0° range.

References

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