

Vapour Chamber Heat Pipe Performance as Seen Through an IR Imaging Camera

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Abstract: The benefit of vapour chambers, commonly known as flat plate heat pipes, in electronics thermal management is that they can significantly reduce the conduction resistance present in the base of large metallic heat sinks. This paper considers an experimental study in determining a vapour chamber heat pipe performance. Using an IR thermal imaging camera, temperature measurement and distribution on the evaporator surface of the heat pipe was recorded. To verify the validity of this technique, steady state and transient analysis of comparative experiments were performed on two vapour chamber heat pipes (a fully functioning vapour chamber heat pipe and a failed vapour chamber heat pipe) and on a solid block of copper. The test-rig set up as well as the experimental results are presented in detail.

Keywords: Vapour chambers; flat plate heat pipes; thermal management; IR thermal imaging

1. INTRODUCTION

Heat pipes have been studied for over 30 years and have been developed into variations each having their own particular application and specific benefits [1,2]. The vapour chamber (VC) is one such variation, utilising the same principle of passive two-phase fluid action to transfer heat with minimal energy loss. This form of heat pipe is formed as a flat sheet which spreads heat across its entire surface, and is commonly integrated into the base of heat sinks in order to reduce thermal spreading resistance as shown in Figure 1 [3].



Figure 1: Vapour Chamber used to spread heat across base of a heat sink (courtesy of Thermacore International)

When integrated into a heat sink, a VC can achieve the following advantages:

- i. Maintain multiple heat generating components mounting plate isothermal whereas standard heat sinks or cold plates will develop uneven heat distributions due to the fluid rising in temperature as it passes from one hotspot to the next.
 - ii. Dissipate higher heat fluxes compared to standard heat pipe as a working fluid in its liquid state is drawn to the hot spots from all surrounding areas, increasing the threshold before dry out.
 - iii. Keep the thermal resistance between a directly mounted heat generating device and the heat pipe vapour space very low (i.e., low temperature difference) by eliminating conduction in saddles or other types of interface blocks.
 - iv. Decrease weight of heat sink as integrating a VC into the base of a heat sink would no longer require the base material to spread the heat. This can allow for a reduction in base size. Additionally, the hollow structure of VC weighs less than an equivalent solid block.
 - v. Conduct heat in one direction (i.e., a thermal diode) with a wick mounted on the evaporator heat can only be transferred unidirectionally to the heat sink.
 - vi. Can be directly retro-fit on base of heat sink. Standard heat pipes would require embedding incurring extra implementation costs.
- The study of performance of VC heat pipe using IR techniques is the most advanced technique used in visually mapping operating parameters of a VC. The use of IR technique also offers the advantage of non-contact and Non Destructive Tests (NDT) to be carried out. The IR method is based on the principle that all objects, above absolute zero, emit infrared radiant heat, at a rate that is directly related to the

temperature of the object. The IR sensor detects the wavelength of the energy emitted by an object and by the use of integral equations, the temperature can be obtained once the body material and surface quality are known. Detailed information on the IR measurement technique can be found in specialised books such as Kaplan [4].

2. EXPERIMENTAL SETUP

The VC heat pipe experimental rig assembly consists of a vapour chamber heat pipe, a cooling assembly of two fans and an aluminium finned heat sink as shown in Figure 2a and 2b.

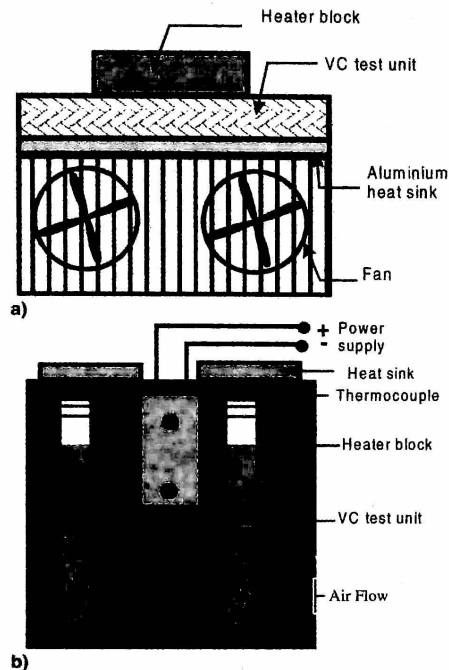


Figure 2: Schematic representation of a test unit assembly a) Cross section b) profile section

Figure 3 shows a simple diagramme of the vapour chamber heat pipe used as a test sample in this experiment. It is made from copper material in which the evaporator and condenser have a rectangular surface shape of 200 mm in width and 250 mm in length. The inner surface of the evaporator is covered with a sintered powder wick to provide capillary forces for the working fluid to be drawn into the heat supply regions. Posts spanning the evaporator and condenser surface and which serve as structural supports against externally applied forces maintain

the small gap between the two surface. In this experimental arrangement, heat from the heater block is supplied from the top surface (i.e., the evaporator) and hence efficient capillary design of the wick materials is essential to overcome gravity forces acting on returning liquid.

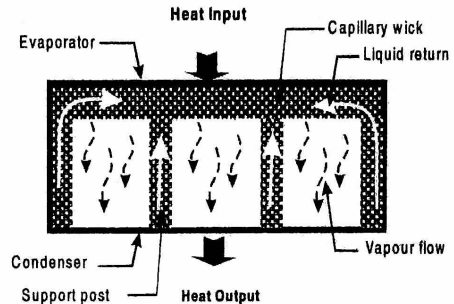


Figure 3: A simplified schematic diagramme of a vapour chamber

Figure 4 shows the experimental set up and associated data acquisition instruments including the IR imaging camera to measure temperature profiles on a test unit. Experimental measurements were conducted on a VC heat pipe sample to determine its operating performance. For a comparative study, tests were also replicated using a solid copper block with the same external dimensions and an identical failed vapour chamber.

The experimental procedure consists of placing a test unit on a cooling assembly made up of two fans and an Aluminium heat sink with a shroud to focus the airflow. Power was delivered through a controlled power supply to two electric heater cartridges placed inside an Aluminium block of 60cm by 90cm. To reduce contact thermal resistance, a thermal interface material was inserted between the base of the aluminium heater block and the VC evaporator surface. The exposed surface of the evaporator of the test unit was then painted black to increase the emissivity of the copper surface. In this experiment a FLIR ThermoCAM SC3000 IR camera was used with a thermal sensitivity of 20 mK at 30°C, an accuracy of 1% or 1 K of full scale for temperatures up to 150 °C, and 2% or 2 K of full scale for temperatures above 150 °C. the procedure for calibrating the readings obtained by the IR camera was conducted by placing a T-type thermocouple on the exposed surface of the test units. The difference between this temperature reading and the IR camera reading at the same point was then used to determine the emissivity of the surface and calibrate the camera readings accordingly. The temperature of the region directly under the heater block was measurement by a T-type thermocouple as the IR camera can not be used to access the temperature profile in that region.

The determination of the VC performance was conducted for various heat loads by using a variable electric power source to supply heat to the block heater. A wattmeter was also used to accurately measure the power supplied. Initial heat input to the VC was set at 200 W and then increased at equal increments of 300 W to a maximum power of 2 kW. At each intermediate power level, the experiment was allowed to run for about 20 minutes so that heat transfer steady state in the VC was reached. The maximum heat supply to the test unit was limited to the VC surface temperature approaching the 100°C threshold.

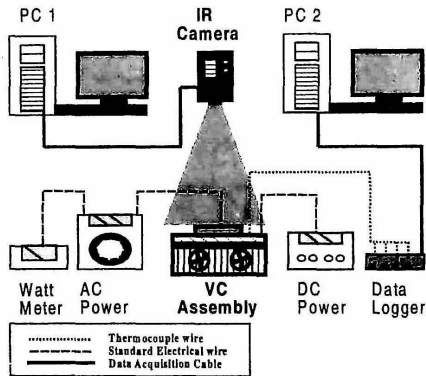


Figure 4: Experimental equipment and setup for determining IR surface gradients of a VC

3. RESULTS AND DISCUSSION

The experimental results of a full functioning VC heat pipe, a solid copper block and a failed VC heat pipe are presented in graphical as well as in visual format as obtained using the IR camera.

The graphical plots show the test units surface temperature over a period of time and at various levels of heat input. The graphs also depict the transient regime of heat transfer in the test unit at the designated monitoring points on the surface of the test unit sample. The IR camera was used to record temperature distribution over the entire test unit surface area for each test case. The recorded data was then used to determine the spreading resistance of all three test unit samples (i.e., a fully functional VC, a solid copper, and failed VC). In this case, the failed VC was a unit that contained a full charge of working fluid, but also contained a quantity of non-condensable gas believed to be approximately 1 atm at room temperature.

3.1 Vapour Chamber heat pipe

Figure 5 shows the VC surface temperature at various transient heat input states. The heat was varied from 200W to 2 kW at an increment of 300W. Temperature variation was measured at 6 points

spreading along the diagonal of the VC with point 1 close to the heater block in the centre to point 6 at the corner of the VC. It can clearly be seen that there is very small temperature difference (in the order of 1°C) except on the measuring point located near the corner.

Figures 6a and 6b show images of temperature distribution on the exposed surface of the VC as taken by the IR camera. Two selected images for heat inputs of 1400 and 2000 W were shown here. It can be seen that the VC surface has nearly an isothermal surface except in the small cold spots around the bottom corners of the VC, which account for the relatively large temperature drop in the corresponding curve of Figure 5. The cold spots at the corner are most likely due to the presence of trapped incondensable gases left inside the VC during the venting process.

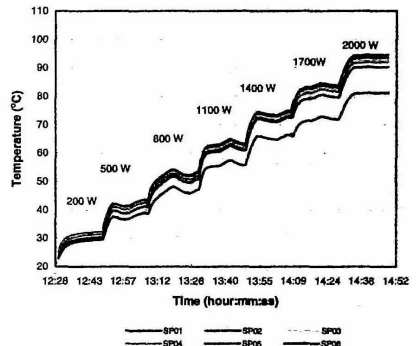


Figure 5: VC transient state over several heat inputs

Transient plots measured using T-type thermocouples recorded similar temperature differences up to a heat input of 1400W. At higher heat inputs however, the temperature difference at different monitoring points began to increase dramatically, indicating that dry out had occurred. This occurrence did not show up on the IR cameras monitoring points as it could not see the dried out evaporator region directly below the heater block.

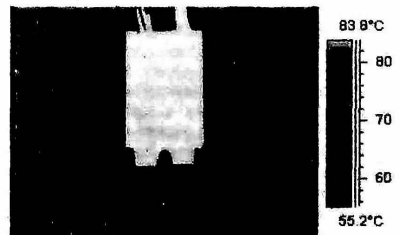


Figure 6a: IR temperature gradients across top surface of vapour chamber at 1400W



Figure 6b: IR temperature gradients across top surface of vapour chamber at 2000W

3.2 Solid Copper Block

Compared to previous results of a fully functioning VC, a solid copper block shows a significantly greater temperature spread across all monitoring points. Figure 7 shows temperature variation at various points of the surface of the block and at various heat inputs. It can also be seen that at heat input of 1700W, the temperature of the block surface is higher than that of a functioning VC with heat input of 2000W.

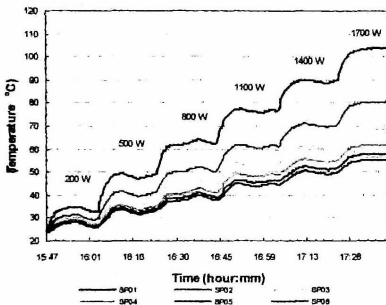


Figure 7: Solid Copper Block temperature variation

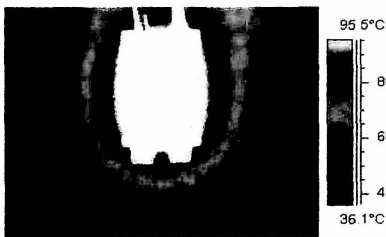


Figure 8: IR Image temperature gradients across top surface of the copper block

At high heat inputs the temperature difference between a monitoring point located near the heater

block (SP 01) and a point located near the corner (SP 06) is about 50°C. This large temperature gradient becomes even clearer when using the IR camera to visualise temperature of the exposed surface, as shown in Figure 8.

3.3 Failed Vapour Chamber heat pipe

Transient temperature variation for the failed VC sample show even greater temperature spreads across its surface compared to a solid copper block (see Figure 9). In this case, the maximum temperature of 100°C on the surface was reached at a heat input of only 1400W. This indicates that the failed VC can effectively be considered as an empty shell, with only its thin copper shell conducting heat and explains the reason that the solid copper block had better performance, as it contains more material to transfer heat from the evaporator to the condenser. The IR image, as shown in Figure 10, also shows temperature gradients similar to that seen in the case of a solid copper block.

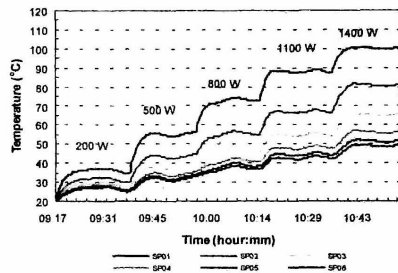


Figure 9: VC shell transients over five power stages

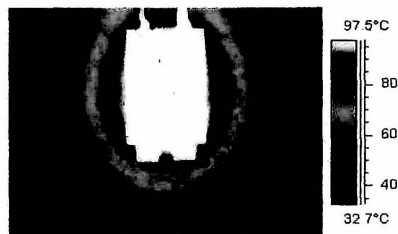


Figure 10: IR temperature gradients across top surface of failed vapour chamber

3.4 Spreading Resistance

In order to gain further insight into the performance measurements of the test units, the spreading resistance was evaluated between two monitoring points located at extreme ends on the test unit surface that is, point SP01 and point SP05 as readings from monitoring point SP06 do not represent the functional part of the unit and hence were

discarded. The spreading resistance was then calculated for each heat input level using the following equation.

$$R_s = \frac{T_{SP01} - T_{SP05}}{Q_{in}}$$

Where,

T_{SP01} and T_{SP05} are temperatures measured at monitoring point SP01 and SP05 respectively and Q_{in} is heat input.

The temperature at monitoring point SP01 was used as a good approximation for the temperature reading directly under the heater block since the IR camera can not take measurements underneath.

The spreading resistance for the three test units is presented graphically in Figure 11 where it can be seen that the thermal spreading resistance of a fully functioning VC unit is very small compared to that of a solid copper block and a failed VC unit.

It can also be seen that the VC unit thermal operates at its optimal conditions at heat input of 1400 W, i.e. with a minimum thermal spreading resistance.

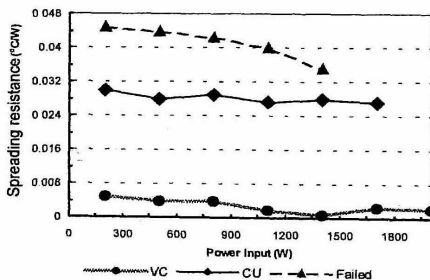


Figure 11: spreading resistance for test units across full input power range

The experimental results presented here did not take into account heat loss from test units through convection and radiation and the electric power supplied to the heater block was assumed to be fully converted by Ohmic effect into heat and transferred through the body of the test unit to the finned heat exchanger/cooling fan. Since the purpose of this experiment was to visualise temperature gradient on the exposed surface it was not possible to thermally insulate this surface to reduce heat losses to the surrounding atmosphere. However refined experiments measurements which take into account heat losses and VC performance under different

orientation conditions will be conducted as a further work.

4. CONCLUSION

The main objective of this study was to investigate the use of an infrared imaging camera for monitoring vapour chamber heat pipe performance. A copper block and a failed vapour chamber were also tested for comparison.

IR images of the vapour chamber revealed a clear isothermal condition over the exposed surface. At heat input of 1400 W the thermal spreading resistance of the VC heat pipe is approximately 0.00071°C/W. Using the IR images however did not identify the dry out condition of the VC as the spreading resistance indicated by the exposed evaporator surface temperatures did not appear to change significantly over the studied range of heat inputs. The condition could however better studied if a method of visualising temperature gradient underneath the heater block was employed.

Unlike the VC heat pipe, the solid copper block had a large temperature gradient across its surface with a thermal spreading resistance of 0.0278 °C/W at 1400W, which is almost 40 times higher than that of the Vapour chamber. The maximum temperature at that point was 90C, 15 C above that of the vapour chamber.

The failed VC test unit showed the worst performance and heat transfer from the evaporator to the condenser was clearly very poor.

The experimental measurements show that using IR camera to evaluate performance of VC heat pipe is a very effective technique. Visualising IR images of temperature gradients on the VC evaporator surface gives a quick snap shot on how well the device functions.

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