Thermal Characteristics of

Wickless Vapor Chambers

Spreading resistance continues to play a dominant role in the overall heat transfer from the source to sink.

With trends towards smaller component footprint and higher power dissipation in electronic components, the need to spread the heat over the base of the heat sink has become very important to reduce the spreading resistance. In some applications such as high power lasers, there might be a need to have a fairly uniform temperature distribution. In such situations a vapor chamber can be one arsenal in the design tools to tackle these problems.

A vapor chamber is basically a hollow container with its internal walls covered with a wick structure that is partially filled with a liquid under vacuum. The heat is transferred to the hot section(evaporator) that causes the liquid to evaporate , thus transferring the heat to the cooler surface (condenser) where it rejects the heat to the heat sink and condenses back to a liquid. The liquid then returns back to the evaporator through the surface tension action of the wicking structure, and hence the cycle is repeated. The vapor chamber can be designed in different ways. It can be designed without any wick, or it can be designed with nanofluids to enhance its performance. In this article we will look at such design options.

Hsieh et al. [1], conducted an experiment to characterize the performance of a wickless vapor chamber. Figure 1 shows their heat spreader vapor chamber. The vapor chamber is 300x300x100 mm. The chamber top and bottom plates are made of 5 mm thick copper plate. The side walls are made from quartz glass for flow visualization. The heater was placed at the bottom surface and the experiment was conducted for different heater sizes, 80x80mm, 100x200mm, and 80x300 mm with the distilled water as the working fluid. The upper section of the chamber was cooled by natural convection.

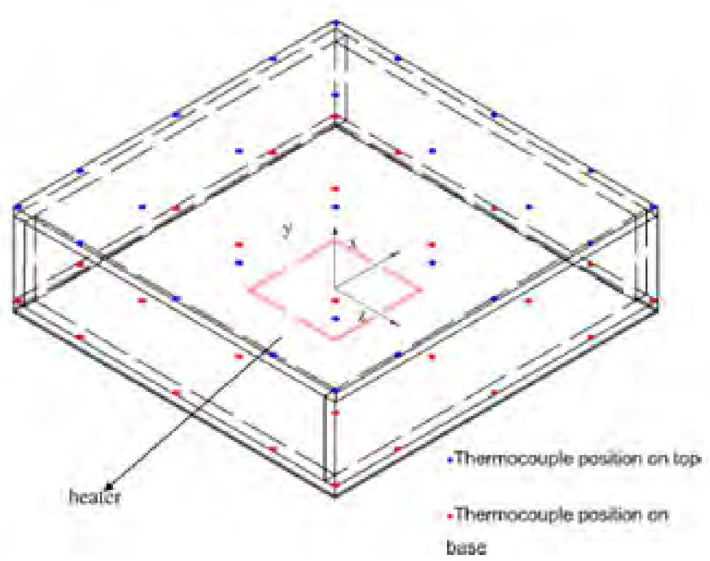

Figure 1. Vapor Chamber Geometry [1]

Figure 2 shows the volume of water needed in the chamber to obtain a minimum junction temperature and avoid dry out as dry out could reduce the vapor chamber effectiveness to a hollow chamber. Junction temperature in this case is defined as the temperature at the center of the foil heater. The volume of the chamber was 8000 ml, and the optimum volume for the water was measured at 2200 ml as approximately 25% of the available volume which is standard for filling vapor chambers and heat pipes.

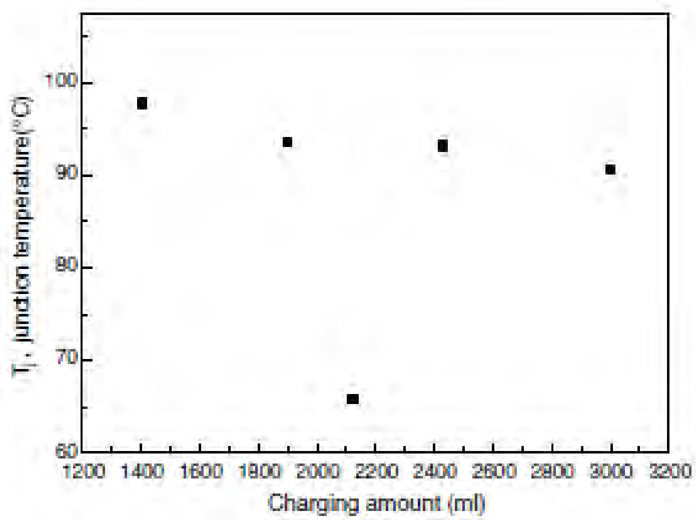

Figure 2. Junction Temperature as a Function of Water Volume [1]

Figure 3 shows the temperature distribution on the evaporator and condenser side along the horizontal Z line at the center of the top and bottom plates for different heater sizes and different fluid saturation temperature. It is shown that the temperature distribution is fairly uniform for different heater sizes and saturation temperatures of 50°C and 70°C on both sides of the chamber. However the distribution is more uniform on the condenser side.

Figure 4 shows the ratio of the spreading resistance of the vapor chamber to that of a comparable size solid copper plate. The graph shows an almost order of magnitude decrease in

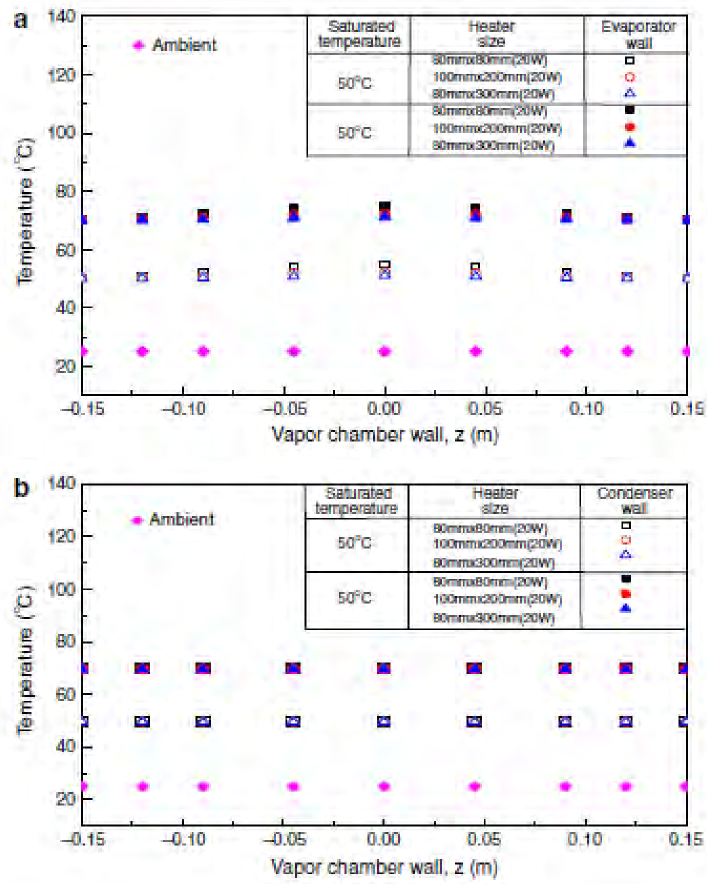

Figure 3. Junction Temperature of Evaporator and Condenser for Different Heat Source Sizes [1]

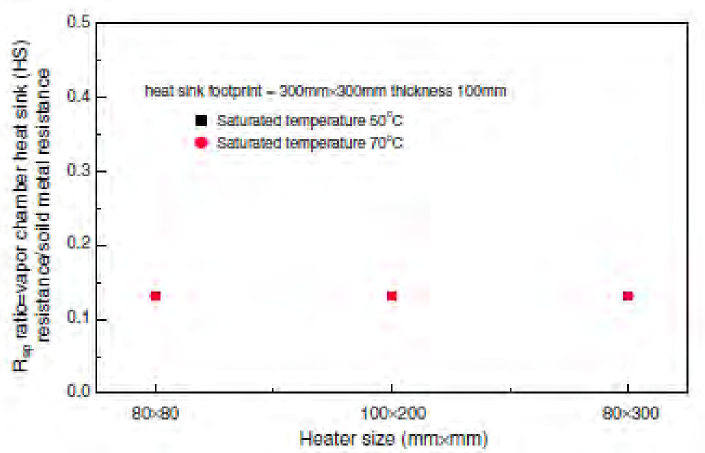

Figure 4. Ratio Of Spreading Resistance of Vapor Chamber To Solid Copper as a Function of Heater Size [1]

spreading resistance. However this graph might be misleading. By increasing the base thickness of the heat sink the spreading resistance decreases and after a certain thickness it actually gets better than vapor chamber. Previous Qpedia articles discussed this issue in detail.

In another experiment Shukla et al. [2] conducted an experiment on a wickless vapor chamber heat sink assembly filled with nanoparticles. Figure 5 shows the schematic of their experiment. Nanoparticles of 99.5% purity were made using laser evaporation technique. The Nano particles were made of copper or aluminum with DI water as the working fluid. The mixture of the DI water and the nanoparticles were kept under ultrasonic cavitation for 30 minutes to ensure the uniformity of the mixture. The Nanoparticle sizes were measured at 70-130 nm.

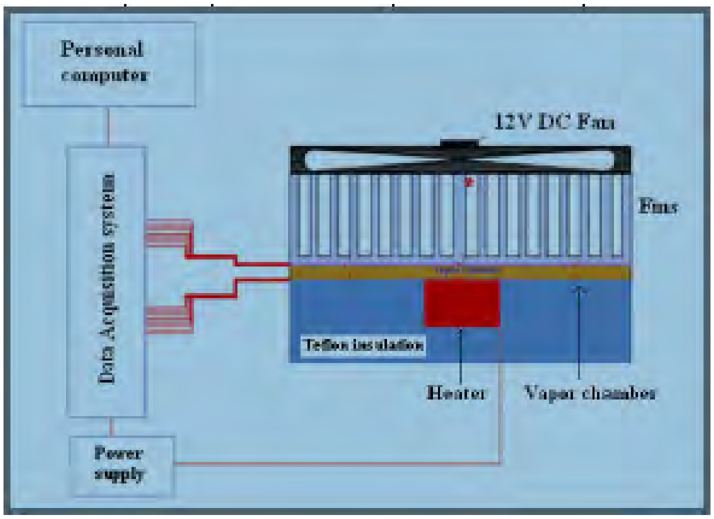

Figure 5. Experimental Set Up of the Vapor Chamber [2]

The vapor chamber was made of copper with dimensions of 78x64x5 mm. A fan heat sink with similar base dimension and 23 mm height was attached to the condenser section of the vapor chamber. The filling ratio of the DI water was 30% of the chamber volume.

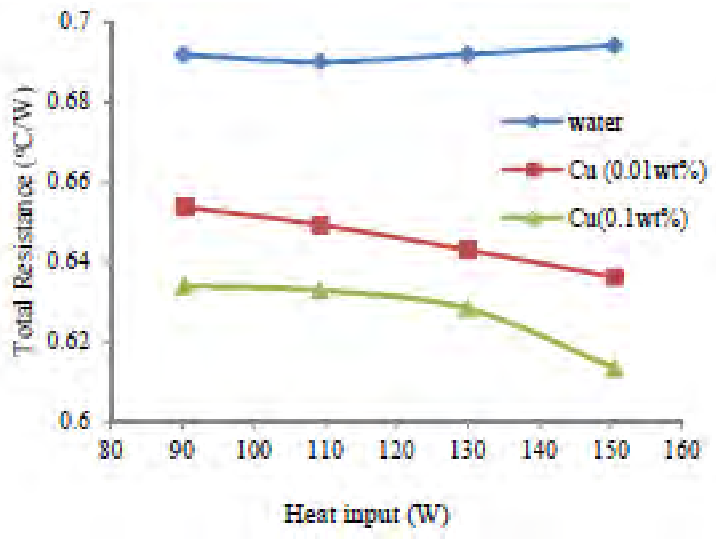

Figure 6. Total Resistance as a Function of Heat Input for Pure Water and Nanoparticle Solutions [2]

Figure 6 shows the total thermal resistance of the vapor chamber for different power inputs for pure water and copper nanoparticles of 0.01% and 0.1% weight ratio. The total thermal resistance is defined as the temperature difference between evaporator and condenser walls divided by the power. This figure clearly shows that the thermal resistance is lower when the water is mixed with nanoparticles. Figure 6 also shows that increasing the copper nanoparticle weight ratio from 0.01% to 0.1% reduces the thermal resistances. The reduction of thermal resistance was 8.3% and 11.6 % for 0.01% and 0.1% ratios (factor of 10). Similar trends was observed for the aluminum nanoparticles with 9.3 and 10.6% reduction in thermal resistance for 0.01and 0.1 % weight ratios.

The authors [2], claim that most of the improvement in thermal resistance come from the enhancement of heat transfer coefficient on the evaporator surface by introducing the Nanoparticles, thus reducing the evaporation thermal resistance. The additional improvement by introducing more nanoparticles increases the thermal conductivity of the mixture. In this case the effective thermal conductivity of the mixture improved by 1% for 0.01% weight ratio and 11% for 0.1% weight ratio. It is desirable to understand the thermodynamic level. Where is the point of diminishing return by increasing the particles.

Even though vapor chambers are useful in reducing spreading resistance, its deployment increases the cost of manufacturing. Care has to be taken to ensure dryout does not occur. The contact between vapor chamber and the heat sink should be free of air voids to minimize the interfacial resistance.

References:

1. **Hsieh, S., Lee, R., Shyu, J., Chen, S., "Thermal performance of flat vapor chamber heat spreader", Energy conversion and management 49(2008) 1774-1784**

2. **Shukla, N., Solomon, B., Pillai, B., "Thermal performance of vapor chamber with nanofluids", Frontiers in heat pipes (FHP), 3, 033004 (2012)**