Industry Developments:

Heat Pipes Providing High Performance

Heat pipes are increasing in type and use for the benefits they provide. Because of their lower total thermal resistance, heat pipes transfer heat more efficiently and evenly than solid aluminum or copper. Heat pipes contain a small quantity of working fluid (e.g. water, acetone, nitrogen, methanol, ammonia). Targeted heat from processors and other components is absorbed by vaporizing the internal fluid. The vapor carries the heat to a condenser region where the condensed vapor transfers its heat to a cooling medium. The condensed working fluid returns to the evaporator via an internal wicking system or by gravity.

Heat pipes have a high thermal conductivity. Solid metal conductors have thermal conductivities ranging from 250 – 1,500 W/m•K. But, heat pipes have thermal conductivities that range from 5,000 - 200,000 W/m•K. Heat pipes transfer heat from the heat source to a condenser over relatively long distances through the latent heat of vaporization of a working fluid. They typically feature an evaporator section (heat input/source), adiabatic (or transport) section, and a condenser section (heat output/sink).

The major components of a heat pipe are a vacuum-tight, sealed containment shell, a working fluid, e.g., water, and a capillary wick structure. The components work together to transfer heat more evenly. The wick structure along the inner surface of the heat pipe provides the capillary action for the liquid returning from the condenser (heat output) to the evaporator (heat input). Because the heat pipe contains a vacuum, the working fluid will boil and take up latent heat at well below its boiling point at atmospheric pressure. [1]

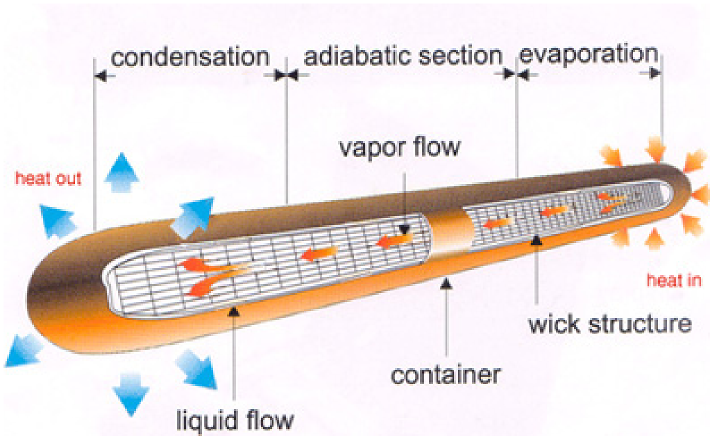

Figure 1. Figure 1: Heat in a Heat Pipe is Absorbed by Liquid at One End. The Liquid Becomes Hot Vapor which Flows to the Cold End where It Condenses and Releases the Latent Heat. The Re-condensed Liquid Flows Back to the Hot End. [2]

Mini Heat Pipes

A recent study comparing cooling methods for handheld instruments demonstrated that conventional mini heat pipes offer very good potential to achieve the needed performance in smaller spaces. [3]

The study explored the thermal management of a sealed enclosure typical of one for housing for handheld instruments. Different active and passive cooling techniques were tested, such as natural convection, conventional heat sinks and copper-water wicked mini-heat pipes. Microelectronics in the enclosure was the internal heat source. The researchers applied and compared various thermal management techniques suitable for maintaining a safe operating temperature inside the enclosure. Transient numerical modeling was used to compare the various techniques available for thermal management. The effects of natural convection inside the enclosure and radiation were taken into account. The results from the CFD simulations were verified with the real time system level experiments.

A series of system level experiments were conducted to establish the effectiveness of different cooling methodologies operating under the actual environmental conditions. Heat removal methods tested were: natural convection and radiation; forced convection using a fan; and the use of three copper, water filled mini heat pipes embedded to in the heat sources and connected to an external actively cooled heat sink. At all ambient conditions tested, the temperature inside the enclosure was highest in the case where no heat pipe or heat sink was used. Even with the usage of a heat sink, the temperature inside the enclosure remained high. But, when heat pipes were used along with an external, active (fan cooled) heat sink, the maximum temperature inside the enclosure reduced significantly by 25°C at the ambient temperature of 45°C.

The study concluded that heat pipes offer an attractive approach to supplement conventional heat sink solutions. They do not replace the conventional heat sink, rather they provide a flexible tool that allows the designer to reconfigure and or extend the performance of conventional heat sinks. Considerably improved heat sink efficiency and performance was achieved for the opto-electronic instrument enclosure by relatively simple integration techniques.

Flat Mini Heat Pipes

A 2011 study by Zaghdoudi et al showed that specially designed flat mini heat pipes were effective at cooling high dissipative electronic components. [4] Their tests included the use of a prototype heat pipe that was tested for its thermal performances under various operating conditions. The flat mini heat sink included a combined capillary structure composed of axial triangular grooves and copper screen meshes. Tests showed the effective thermal conductivity of the flat mini heat sink could reach 2 to 2.5 times that of copper.

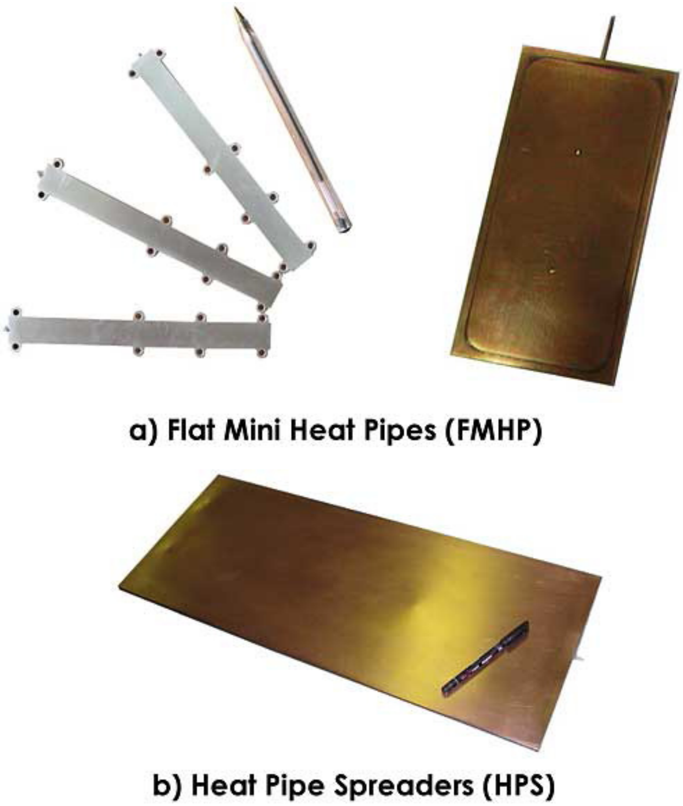

Figure 2. Examples of Flat Mini Heat Pipes that Can Be Used for Cooling Microprocessors, Power Modules and Other Components. [5]

The authors integrated these heat pipes in electronic cards using different mounting technologies and two substrates: alumina and epoxy FR4. The range of operating conditions they tested included high power dissipation on the card, high heat fluxes, and different air temperatures. Their thermal measurements showed that the use of heat pipes allowed for significantly reduced temperature gradients and maximum chip temperature decrease. The average chip temperature decrease due from the use of the mini heat pipe was about 10°C for both substrates used.

Heat Pipes in Space

On the International Space Station, miniature wire heat pipes were used to study the process of fluid dynamics in microgravity. A fluid mechanics test was performed on three mini heat pipes containing distilled water under different pressures. The goal was to assess the respective levels of cooling efficiency.

The equipment consists of a single unit, which accommodates two heat pipes and a data acquisition system. Distilled water in amount of 50 and 60 ml was used as a coolant. Each miniature heat pipe is divided in length to three different parts: an evaporator (20 mm), an adiabatic section (50 mm) and a capacitor (30 mm).

Figure 2. A Test Unit Containing Heat Pipes and a Data Acquisition System Used to Study the Processes of Fluid Dynamics in the Microgravity Conditions Aboard the International Space Station. [6]

The heat was transferred to the evaporator by an electric heater attached with the use of thermal grease. The heat was removed from the capacitor through a copper radiator and two cooling fans. The heat was supplied to the system gradually with the use of an electric heater through a miniature heat pipe. The system functioning was verified under seven different modes at power levels from 5 W to 35 W. To control the temperature variation along the heat pipe, three thermocouples were attached at its surface (Omega T-type), one of which had a direct contact with the data acquisition board. The rest of the thermocouples were accommodated on the heat distributor and insulation. All data was stored on the memory map, which is returned to the ground upon the experiment completion. Results of the tests are available from the ISS Program Science Office.

Water Still the Preferred Fluid

In another recent study, the main purpose was to examine the comparative properties of different fluids to determine the more effective choices for use in heat pipes. The properties studied were those that affected the ability to transfer heat and the compatibility with the case and wick material.

Among the considerations the study recommends when choosing a working fluid are:

- Good thermal stability
- Wettability of wick and wall materials
- Vapor pressures not too high or low over the operating temperature range
- High latent heat
- High thermal conductivity
- Low liquid and vapor viscosities
- High surface tension
- Compatibility with wick and wall materials

The study determined that water is the best working fluid for most of the limits compared to the other fluids tested: methanol and acetone. Water was most effective in its compatibility with capillary systems. [7]

References:

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