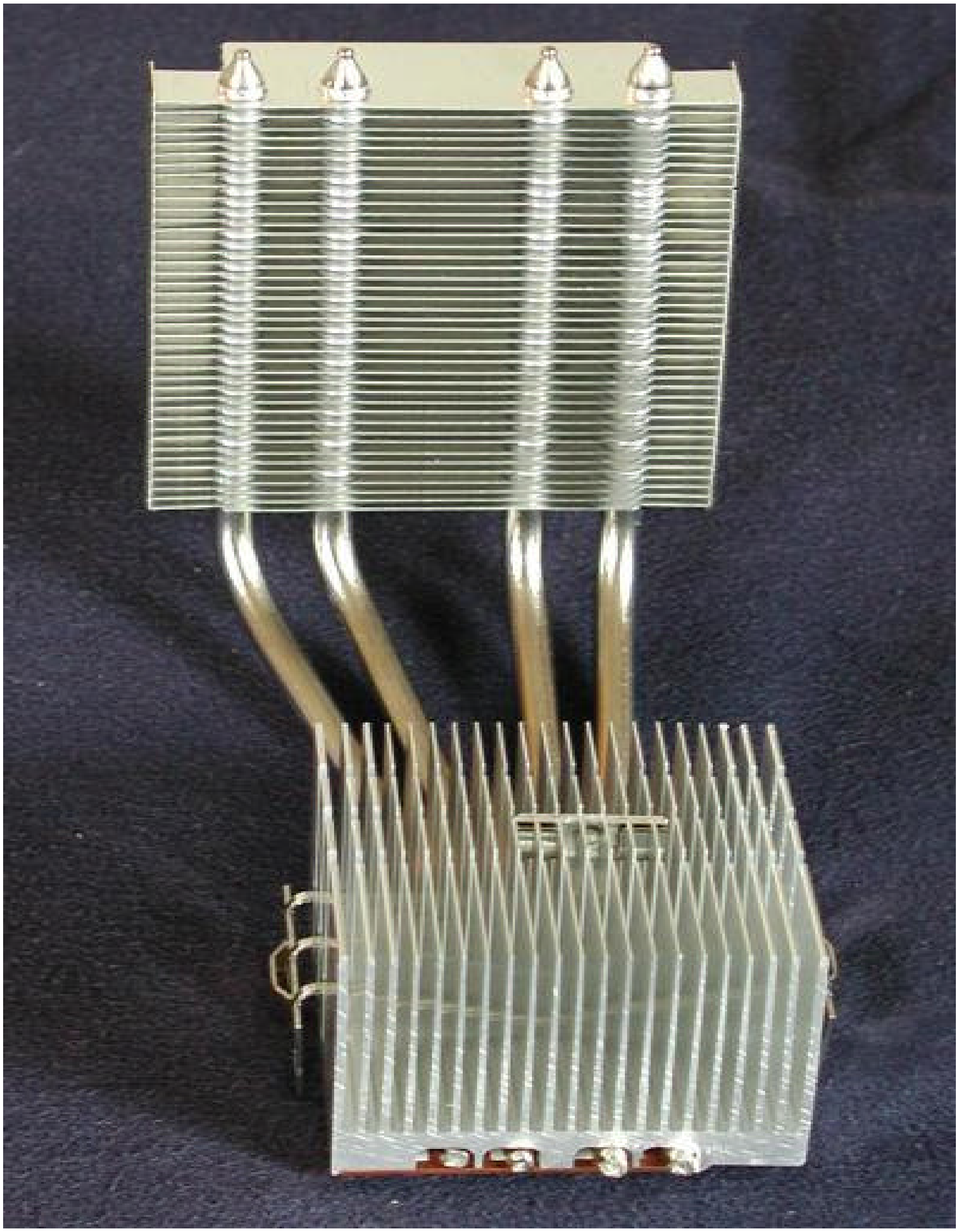


Heat Pipes for Electronics Cooling

Alok Bhatt
ME-211
Instructor: Dr. Younes Shabany
Mechanical Engineering Department
San Jose State University
Spring 2004

Preface

The continuous increase of system power and the decrease of available volume present interesting challenges in the thermal management of electronics. Traditional design has relied on natural convection from a heat sink placed directly on the device. With the increasing power of today's devices, it has been necessary to add a fan to these local heat sinks. Fan sinks placed directly over the device occupy the most valuable real estate and can interfere with the placement of add-on boards and other system components. Heat pipe heat sinks provide the system designer with a powerful tool. The heat pipes transport heat away from the obstructions and constraints of neighboring boards to where it can be conveniently dissipated. The ability of the heat pipe to be formed to meet location and space availability permits the heat pipe heat sink system to provide the maximum effective heat sink surface area with the minimum volume demand. A heat pipe heat sink is a passive cooling device that requires no moving parts, and operates silently and reliably. Additionally, heat pipe technology is emerging as a cost-effective thermal design solution. The increasing power and shrinking size of electronics components presents increasing thermal management challenges. While solid metal conductors such as aluminum extrusions may provide acceptable cooling for individual components in certain situations, board level solutions using more advanced cooling technologies are needed in a growing number of applications. Heat pipes have emerged as an effective and established thermal solution, particularly in high heat flux applications and in situations where there is any combination of non-uniform heat loading, limited airflow over the heat generating components, and space or weight constraints [3] . This paper talks about some of the modern trends in heat pipe technology available in the market today.

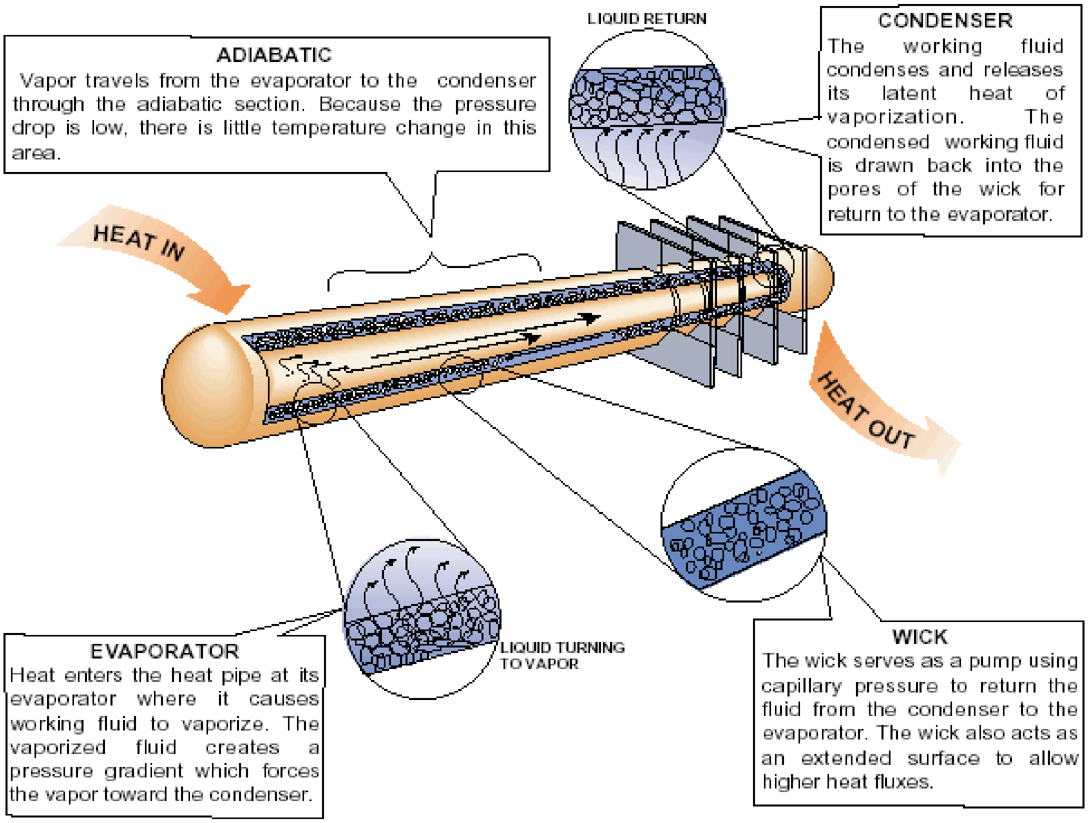
Introduction

Historically, the use of metallic heat sinks has been sufficient to provide the required thermal management for most electronic cooling applications. However, with the new breed of compact devices dissipating larger heat loads, the use of metallic heat sinks is sometimes limited due to the weight and physical size required. [2] Accordingly, the use of heat pipes is becoming a solution of choice. The performance of natural convection heat sinks is directly dependent on the effective surface area; more effective surface area results in better performance. A heat pipe embedded into the base material of a standard aluminum extrusion can reduce the overall temperature difference along the base material, tending to isothermalize the base material. In essence the localized heat source is spread equally along the length of the heat pipe, increasing the overall efficiency of the heat sink. Although an embedded heat pipe heat sink is slightly more expensive due to the added cost of the heat pipe, it is an easy method of improving the performance of a marginal extrusion. The more elegant approach is to design a heat sink that fully utilizes the characteristics of a heat pipe. Typical extruded heat sinks have limited aspect ratios and thick fins, which results in lower surface area per length. The material thickness adds unnecessary weight, and more importantly obstructs the cooling air flow. To alleviate the extrusion limits, bonded fin heat sinks have been developed which allow the use of a tall, thin fin, which optimizes cooling flow. But bonded fin heat sinks can also be limited by the conduction losses in the base plate for concentrated heat sources. A heat pipe used in conjunction with parallel plate fins provides more efficient surface area with minimum volume demands. This design application is useful when there is not enough physical volume, or airflow above the device to use an extrusion, and allows the designer much latitude in component arrangement. The heat pipe can transport the heat to a "remote" parallel plate fin stack that has enough volume to dissipate the heat. Heat pipes can be designed into most electronic devices for various power levels, and may even allow the use of a natural convection heat sink.

The following sections give an overview of heat pipe operation and limitations.

Heat Pipe Operating Principles

A heat pipe is a passive heat transfer device with an extremely high effective thermal conductivity. Its two-phase heat transfer mechanism results in heat transfer capabilities from one hundred to several thousand times that of an equivalent piece of copper. Heat pipes are sealed vacuum vessels that are partially filled with a working fluid, typically water in electronic cooling, which serves as the heat transfer media. The heat pipe envelope is made of copper in a numerous shapes including cylindrical, rectangular, or any other enclosed geometry. The wall of the envelope is lined with a wick structure, which provides surface area for the evaporation/condensation cycle and capillary capability. Since the heat pipe is evacuated and then charged with the working fluid prior to being sealed, the internal pressure is set by the vapor pressure of the working fluid. As heat is applied to the surface of the heat pipe, the working fluid is vaporized. The vapor at the evaporator section is at a slightly higher



ADIABATIC
Vapor travels from the evaporator to the condenser through the adiabatic section. Because the pressure drop is low, there is little temperature change in this area.

CONDENSER
The working fluid condenses and releases its latent heat of vaporization. The condensed working fluid is drawn back into the pores of the wick for return to the evaporator.

EVAPORATOR
Heat enters the heat pipe at its evaporator where it causes working fluid to vaporize. The vaporized fluid creates a pressure gradient which forces the vapor toward the condenser.

WICK
The wick serves as a pump using capillary pressure to return the fluid from the condenser to the evaporator. The wick also acts as an extended surface to allow higher heat fluxes.

Figure 1: Heat Pipe operation (Courtesy Thermacore Inc.)

temperature and pressure than other areas. This creates a pressure gradient that forces the vapor to flow to the cooler regions of the heat pipe. As the vapor condenses on the heat pipe walls, the latent heat of vaporization is transferred to the condenser. The capillary wick then transports the condensate back to the evaporator section. This closed loop process continues as long as heat is applied. The capillary pumping pressure generated by the wick structure is critical to maintaining the circulation of the fluid against the liquid and vapor flow losses, and against adverse body forces, such as gravity. [1]

Heat Pipe Wick Structures [3]

The main distinction of heat pipes, besides working fluid, is the wick structure. There are several types of wick structures used in copper/water heat pipes: screen, grooves, felt, and sintered powder. Sintered powder metal wicks offer several advantages over other wick structures. One advantage of a heat pipe with a sintered powder wick is that it can work in any orientation, including against gravity (the heat source above the cooling source). The power transport capacity of the heat pipe will typically decrease as the angle of operation against gravity increases. Since groove and screen mesh wicks have very limited capillary force capability, they typically can not overcome significant gravitational forces, and dry out generally occurs. An emerging advantage of the sintered powder wick is its ability to handle high heat fluxes. Since sintered powder wicks are 50% porous, accordingly there is a large surface area available for evaporation. Also, the nominal pore distribution within a typical sintered powder wick structure provides a mechanism to accommodate vapor and liquid simultaneously. Typical sinter powder wicks handle 50 W/cm2, and have been tested to 250 W/cm2. In comparison, a groove wick will nominally handle 5 W/cm2 and a screen wick will nominally handle 10 W/cm2. Additionally, since a sintered powder wick is integral with the heat pipe envelope, and the fluid charge is only enough to saturate the wick, the heat pipe is able to be subjected to freeze/thaw cycles with no degradation in performance. The above attributes make the sintered powder wick the optimum structure for many thermal management solutions.

When to Consider a Heat Pipe Thermal Solution [5]

Thermal system designers that have the following constraints would consider a heat pipe thermal solution:

• **Limited Height Budget:** In some applications, the height over the electronic device may not provide sufficient space to provide direct cooling at this location. A heat pipe in this situation is used to move the heat to a location where it can be effectively dissipated by natural or forced convection.

• **Limited or Zero Electrical Power Consumption:** Cooling with a fan requires electricity. In some portable applications, a fan reduces battery power and limits the useful operating time of the product. A heat pipe, in this situation, allows the developer to acquire additional surface area for heat rejection by natural convection, thus eliminating the need for a fan. If volume constraints limit the use of a natural convection cooling solution, a heat pipe to a miniature fan/sink might be more economical than a large system fan solution.

• **Zero Noise or Noise Reduction:** Cooling by natural convection eliminates fan noise. If volume constraints limit the use of a natural convection cooling solution, a heat pipe to a miniature fan/sink will result in less noise than a large system fan solution.

• **Low Maintenance/ High Reliability:** All electro-mechanical devices such as fans have finite life. A heat pipe thermal solution has no moving parts to fail; consequently product maintenance requirements are eliminated or reduced.

• **Sealed Enclosure Cooling:** In some applications, the device to be cooled will be in a sealed enclosure to protect it from the environment. An example is an Industrial PC located on the dirty shop floor. Heat in this situation, needs to be rejected from the outside of the sealed enclosure. The heat pipe provides a thermal path to the enclosure wall.

• **Stagnation Regions:** In some situations, an electronic device can be located in a region of poor air circulation inside the enclosure. A heat pipe in this situation is used to move the heat to region where there is adequate air circulation. For example, air from a system fan is directed or ducted over the main CPU, thereby, starving other electronics within the enclosure of cooling air. Heat pipes are then used to interface with the ducted air stream.

- **Low Weight:** Attaching a heat sink to a printed circuit board places strain on the board. If the heat sink is too heavy it can warp and damage the board. The ultimate goal is a heat sink that has a low thermal resistance and is lightweight. Extrusion type heat sinks that mount directly over top the electronics are getting quite large for the amount of heat that must be dissipated. Heat pipe thermal solutions are offering the best performance at the lowest weight.

Operating Limitations [5]

Since the heat pipe benefits from the phase change of the working fluid, the thermodynamics of the process are critical. The operation of the heat pipe is limited by several operating phenomena. Each of these limitations is dependant on the wick structure, working fluid, temperature, orientation, and size of the heat pipe. Below is a brief description of each of the limitations:

Capillary Limit: The wick structure of the heat pipe generates a capillary pressure, which is dependent on the pore radius of the wick and the surface tension of the working fluid. The capillary pressure generated by the wick must be greater than the sum of the gravitational losses, liquid flow losses through the wick, and vapor flow losses. The liquid and vapor pressure drops are a function of the heat pipe and wick structure geometry (wick thickness, effective length, vapor space diameter, etc) and the fluid properties (latent heat, density, viscosity, etc). A critical heat flux exists, that balances the capillary pressure with the pressure drop associated with the fluid and vapor circulation. For horizontal or against gravity (evaporator at a higher elevation than the condenser), the capillary limit is the heat pipe limit. For gravity aided orientations, the capillary limitation may be neglected, and the flooding limit may be used if the heat pipe can have an excess fluid charge.

Boiling Limit: As more heat is applied to the heat pipe at the evaporator, bubbles may be formed in the evaporator wick. The formation of vapor bubbles in the wick is undesirable because they can cause hot spots and obstruct the circulation of the liquid. As the heat flux is increased, more bubbles are formed. At a certain heat flux limit, the bubble formation completely blocks the liquid flow. This limitation is associated to a radial heat flux (heat is applied to the perimeter of the heat pipe). The boiling limitation is typically a high temperature phenomena.

Sonic Limit: In a heat pipe of constant vapor space diameter, the vapor flow accelerates and decelerates because of the vapor addition in the evaporator and the vapor removal in the condenser. The changes in vapor flow also change the pressures along the heat pipe. As more heat is applied to the heat pipe, the vapor velocities generally increase. A choked flow condition will eventually arise, where the flow becomes sonic. At this point, the vapor velocities can not increase and a maximum heat transport limitation is achieved. The heat flux that results in choked flow is considered the sonic limit.

Entrainment Limit: Since the vapor and the liquid move in opposite directions in a heat pipe, a shear force exists at the liquid-vapor interface. If the vapor velocity is sufficiently high, a limit can be reached at which the liquid will be torn from the pores of the wick and entrained in the vapor. When enough fluid is entrained in the vapor that the condensate flow is stopped, abrupt dry-out of the wick at the evaporator results. The corresponding heat flux that results in this phenomenon is called the Entrainment Limit. The Entrainment Limit is typically not the bounding value.

Flooding Limit: The flooding limit is only applicable to gravity aided orientations with excess fluid. The wick structure is saturated and the excess fluid results in a “puddle” flow on the surface of the wick structure. The flooding limit, similar to the entrainment, occurs when high vapor velocities preclude the fluid that is flowing on the surface of the wick to return to the evaporator. The vapor shear hold up prevents the condensate from returning to the evaporator and leads to a flooding condition in the condenser section. This causes a partial dry-out of the evaporator which results in wall temperature excursions or in limiting the operation of the system.

Heat Pipe Operating Predictions [1]

Predicting or developing an optimum heat pipe thermal solution requires use of theoretical and empirical relationships, wisdom and design experience, and knowledge of the application design parameters and system flexibilities. For design concepts and preliminary designs, it can be useful to have a guideline for heat pipe performance. These are general performance guidelines based on a “standard” powder metal wick structure. Alternative powders and production techniques are available that may increase the performance in upwards of 500%. The above operating limitations can be summarized to predict heat pipe performances based on three orientation categories.

Gravity Aided: The evaporator is at a lower elevation than the condenser. The Gravity Aided orientation is the most efficient, since the heat pipe acts as a thermosyphon and gravity will return the condensed fluid to the evaporator. A sintered powder wick structure may still be needed to handle the heat flux in the evaporator. Heat pipe operation is typically limited by the flooding limit or the boiling limit (at elevated temperatures above 175°C). These two limitations are most greatly affected by the diameter of the heat pipe; a larger diameter heat pipe will carry more power. Figure 2 can be used as a guideline for the selection of a "standard" copper-water powder wick heat pipe in the gravity aided orientation. The area below each curve is the allowable operating region. For the miniature heat pipes (3mm and 4mm) use the greater of the "Gravity Aided" and "Horizontal" curves.

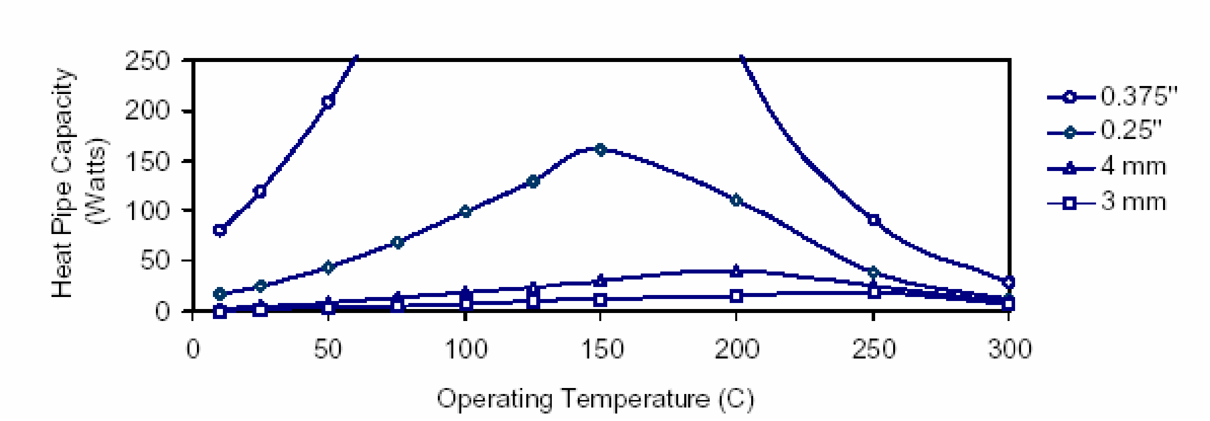


Figure 2: Performance Cure for gravity aided Operation

Horizontal: The Horizontal orientation relies on the wick structure to provide the capillary pressure to return the condensed fluid to the evaporator. The heat pipe operation is typically limited by the Capillary Limit. This limitation is greatly affected by the diameter of the heat pipe (a larger diameter heat pipe will carry more power) and the length of the heat pipe (a longer heat pipe will carry less power). A useful parameter is the Effective Length:

LEff = LAdiabatic + ½ (LEvaporator + LCondenser)

Figure 3 can be used as a guideline for the selection of a "standard" copper-water powder wick heat pipe in the Horizontal orientation. The capacity of a heat pipe can be determined by taking the appropriate value from the graph in "Watt-Inches" and dividing by the Effective

Length. *Ex.*: A 0.25 inches OD heat pipe with a total length of 8 inches, an evaporator length of 1 inch, and a condenser length of 5 inches operated at 25°C. The effective length is 5 inches. Therefore the heat pipe can carry 20 Watts (100 Watt-Inches from Figure 2 ÷ 5 inches).

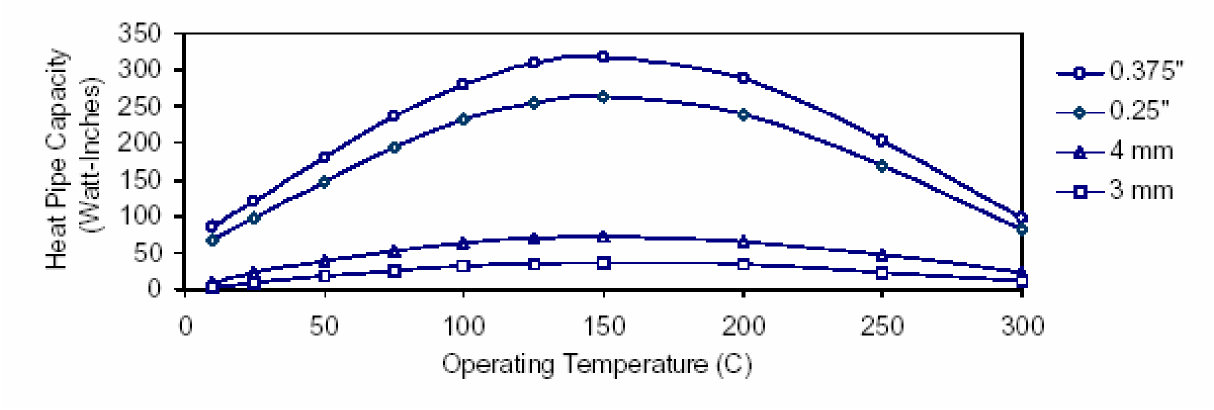


Figure3: Performance Cure for horizontal operation

Against Gravity: The evaporator is at a higher elevation than the condenser. Heat pipe operation in the Against Gravity orientation relies solely on the wick structure to return the condensed fluid up to the higher evaporator. Again the heat pipe operation is limited by the Capillary Limit. A larger elevation difference between the evaporator and the condenser results in a lower power capacity. As shown by the above figures, the orientation and layout of a heat pipe design are critical. When the design allows, the heat source should be located below or at the same elevation as the cooling section for best performance. This orientation allows gravity to aid the capillary action, and results in a greater heat carrying capability.

Heat Pipes: The Silent Way to Manage Desktop Thermal Problems [5]

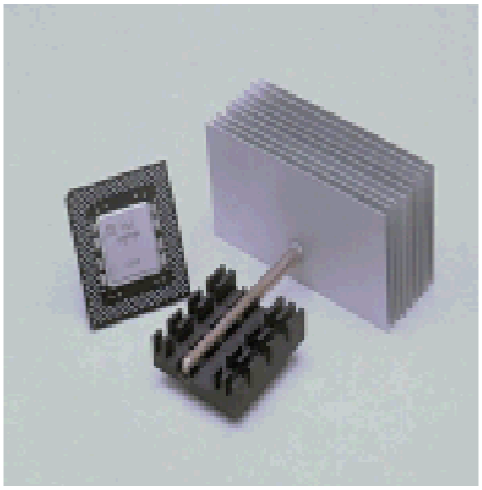
The continuous increase of system power and the decrease of available volume present interesting challenges in the thermal management of desktop computers. Traditional desktop computer design has relied on natural convection from a heat sink placed directly on the processor. With the increasing power of today's processors, it has been necessary to add a processor fan to these local heat sinks. Mechanical components with moving parts are the most unreliable components in desktop computers. The use of heat pipes may eliminate the use of the processor fans and their inherent reliability concerns. A heat pipe heat sink is a passive cooling device that requires no moving parts, and operates silently, and more importantly, reliably. Additionally, heat pipe Technology is emerging as a cost-effective thermal design solution for the desktop industry.

Fan sinks placed directly over the processor occupy the most valuable real estate in a computer and can interfere with the placement of add-on boards and other system components. Heat pipe sinks provide the system designer with a powerful tool. The heat pipes transport heat away from the obstructions and constraints of neighboring boards to where it can be conveniently dissipated. The ability of the heat pipe to be formed to meet location and space availability and its characteristic low .T as a function of length permit the heat pipe heat sink system to provide the maximum effective heat sink surface area with the minimum volume demand. The heat load can be conducted to open areas within the system.

The computer industry has recognized the importance of thermal management and that identifying the component’s thermal necessities at the beginning of the design process will eliminate costly redesigns. The complexities of thermal management are compounded due to the increasing heat fluxes concentrated on decreasing component sizes. The concentrated heat sources are making standard extruded heat sinks less effective due to the inherent conduction losses. In some cases, conduction losses result in temperature gradients of 5 to 10°C between the center and the extremities of the extrusion. Due to this, the end fins are much cooler, and therefore less effective. This is an ideal application for heat pipe technology. Although an embedded heat pipe heat sink is slightly more expensive due to the added cost of the heat pipe, it is an easy method of improving the performance of a marginal extrusion. Another approach is to design a heat sink that fully utilizes the characteristics of a heat pipe. Typical extruded heat sinks have limited aspect ratios and thick fins, which results in lower surface area per length. The material thickness adds unnecessary weight, and more importantly obstructs the cooling air flow. To alleviate the extrusion limits, bonded fin heat sinks have been developed which allow the use of a tall, thin fin, which optimizes cooling flow. But for concentrated heat sources, the bonded fin heat sinks are still limited by the conduction losses in the base plate. A heat pipe, used in conjunction with parallel plate fins, provides more efficient surface area with minimum volume demands. But, in order to design a manufacturable, efficient heat pipe heat sink, the operation of the heat pipe needs to be explained.

Heat Pipe Heat Sinks

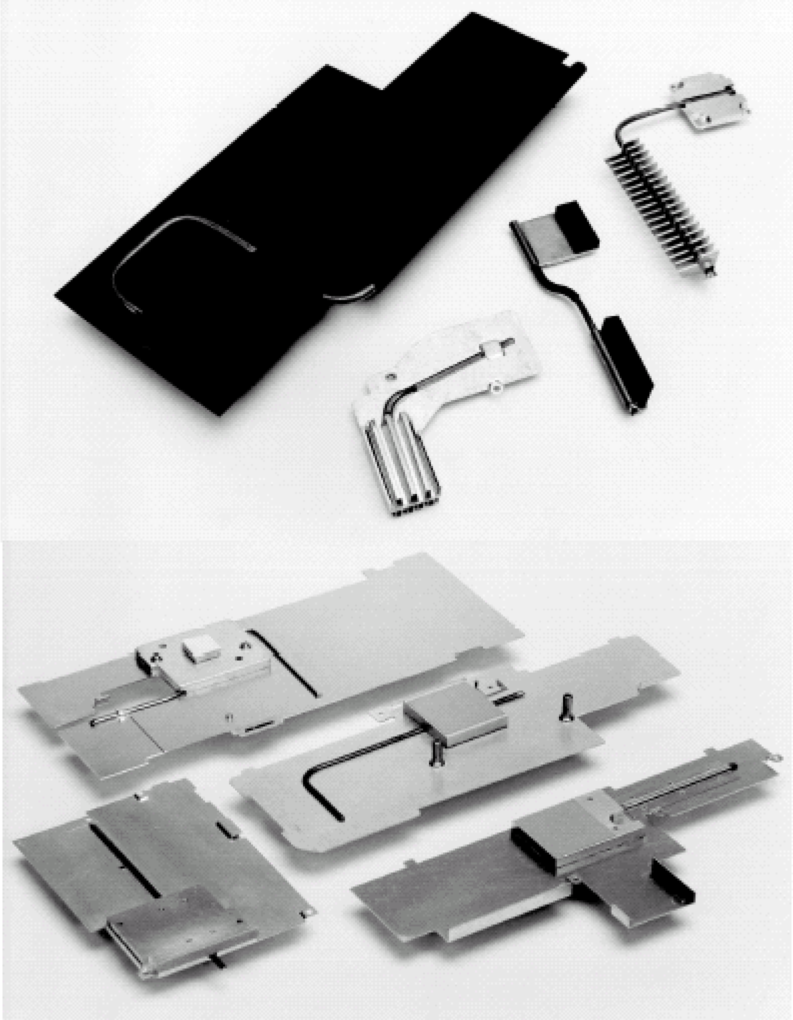
The use of metallic heat sinks has provided and still supplies the required thermal management for most desktop applications. But with new processors dissipating more than 20 watts, the use of metallic heat sinks in the natural convection regime is no longer feasible due to the weight and physical size required. Systems now require additional fans force air through the heat sink located on the processor. design alternative that takes full advantage of the heat pipe characteristics is a remote fin stack design, shown in Figure This design application is useful when there is not enough physical volume, or air flow above the processor to use "over the processor" extrusion, and allows the designer much latitude in component arrangement. The heat pipe can transport the heat to a "remote" location that has enough volume for a natural convection design, or an induced draft from an existing fan, such as the power supply fan.



ADVANCED HEAT PIPE THERMAL SOLUTIONS FOR HIGHER POWER NOTEBOOK COMPUTERS [7]

In their excellent paper on advanced heat pipe thermal solutions for notebook computer by Andre Ali (Intel Inc.), Robert Dehoff and Kevin Gurbb(Thermacore Inc.); they describes the thermal resistance circuit for the heat flow through various components like heat pipe, EMI, fins in a notebook computer.

The first time a heat pipe was used in a notebook computer was in 1994. Up until that time, simple metallic heat sinks were used to control the CPU temperature. The introduction of heat pipes in to notebooks was thought of as a radical evolution in thermal management. Heat pipes were first used to take the heat from the heat source, i.e., CPU and transfer it to another location inside the notebook, i.e., a remote heat sink. The location was usually the Electromagnetic Interference (EMI) shield or an internal metal structure. The first notebook designs used simple mounting blocks that were attached to the CPU. The heat pipe was usually epoxied into a groove in the mounting block. The other end of the heat pipe would then be epoxied to an aluminum plate that contacted the EMI shield or was integrated into the mechanical structure of the notebook. The heat pipe was typically flattened to reduce its height and increase contact area of the heat pipe. Typical thermal resistances of the early heat pipe thermal modules were in the range of 2 to 4 °C/W with the dissipation power around 6 watts. Figure illustrates some of the heat pipe designs. The heat pipe was the ideal thermal solution, but its one major drawback was cost.

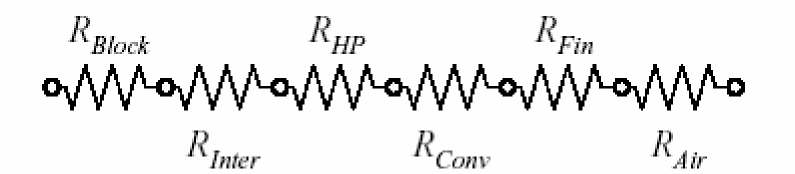


CURRENT NOTEBOOK HEAT PIPE DESIGNS

Almost every current notebook computer uses a heat pipe in its’ thermal management design. Most of the current notebook's heat pipe- heat sinks use a 3 or 4 mm diameter heat pipe that carries the power from the CPU to a large aluminum plate. The heat then conducts Fig 4: Notebook heat pipe heat sinks into the EMI shield of the keyboard, through the keyboard, and by natural convection and radiation to the ambient air. This type of passive design has been a very effective thermal management technique for CPU’s with powers less than 7 watts. There have also been designs that use the heat pipe to carry the heat from the CPU to a Magnesium Die Cast heat sink. Cost of the more recent designs incorporates a heat sink/fan/vent with the use of a heat pipe. The later concept is widely known in the industry as a Remote Heat Exchanger (RHE). The design intent of a RHE is to allow the notebook designer to locate the CPU independent of the heat sink. This allows the notebook designer to design the most effective heat exchanger and optimal airflow path. The optimal design helps to reduce airflow requirements and noise. One of the limiting factors is the volumetric airflow that current DC fans can produce reliably.

Because of size and voltage restrictions, fans must run at higher RPMs. This of course has an effect on noise and life of the fan. Most applications use a remote fin stack design, which consist of an aluminum evaporator block (heat input section), the heat pipe (heat transport section), and aluminum fins (heat sink section).

A resistance network, analogous to electrical circuits, is the quickest (and crudest) way to predict the overall performance of a parallel plate/heat pipe heat sink. Although a more detailed model can readily be created (and should be) using a computational fluid dynamics package, the resistance network is a first quick and crude approach to determine design feasibility. The heat pipe heat sink can be represented by a resistance network, as shown in Figure. Although this network does not include the interface between the device and heat sink, this resistance can easily be added.



Each of the resistances can be solved to calculate an associated temperature drop. The following is a brief explanation of the network. The conductive losses that are associated with the evaporator block (*RBlock*) are governed by Fourier's Law, therefore:

$$\Delta T_{Block} = Q \; t_{Block} \big/ k_{Block} \quad A_{Block}$$

The loss associated with the interface between the evaporator block and the heat pipe (*RInter*) can be calculated using the thermal resistance of the interface material, which is typically solder (*RInter*. 0.5 °C/W/cm2) or thermal epoxy (*RInter* . 1.0 °C/W/cm2), and the interface area.

$$\Delta T_{Inter} = Q \; R_{Inter} \big/ \pi \; D_{HP} \; L_{Evap}$$

The detailed analysis of heat pipe is rather complex. The total thermal resistance of a heat pipe is the sum of the resistances due to conduction through the evaporator section wall and wick, evaporation or boiling, axial vapor flow, condensation, and conduction losses back through the condenser section wick and wall. A rough guide for a copper/water heat pipe with a powder metal wick structure is to use 0.2 °C/W/cm2 for the thermal resistance at the evaporator and condenser (applied over the heat input/output areas), and 0.02 °C/W/cm2 for axial resistance (applied over the cross sectional area of the vapor space), in the following equation:

$$\Delta T_{HP} = \frac{QR_{Evap}}{\pi D_{Hp} L_{Evap}} + \frac{QR_{Axial}}{.025\pi D_{VS}^{2}} + \frac{QR_{Cond}}{\pi D_{Hp} L_{Cond}}$$

The resistance in transferring the heat from the fin to the air (*RConv)* is calculated using the convection coefficient as follows:

$$\Delta T_{Conv} = Q \big/ h \; A_{Fin}$$

The conductive losses that are associated with the fin (*REff*) are governed by the fin efficiency as defined as:

$$\eta_{Fin} = \tanh\left(m_{Fin} \; L_{Eff}\right) \big/ \left(m_{Fin} \; L_{Eff}\right)$$

where:

$$m_{Fin} = \sqrt{2\,h \big/ k_{Fin} \; t_{Fin}}$$

then:

$$\Delta T_{Fin} = \Delta T_{Conv} \left(1 - \eta_{Fin}\right)$$

The effective air rise can be calculated by using the bulk fluid properties:

$$\Delta T_{Air} = \frac{1}{2}\left(Q \big/ \dot{m} \; C_P \right)$$

The overall performance of the sink is the sum of the individual temperature drops:

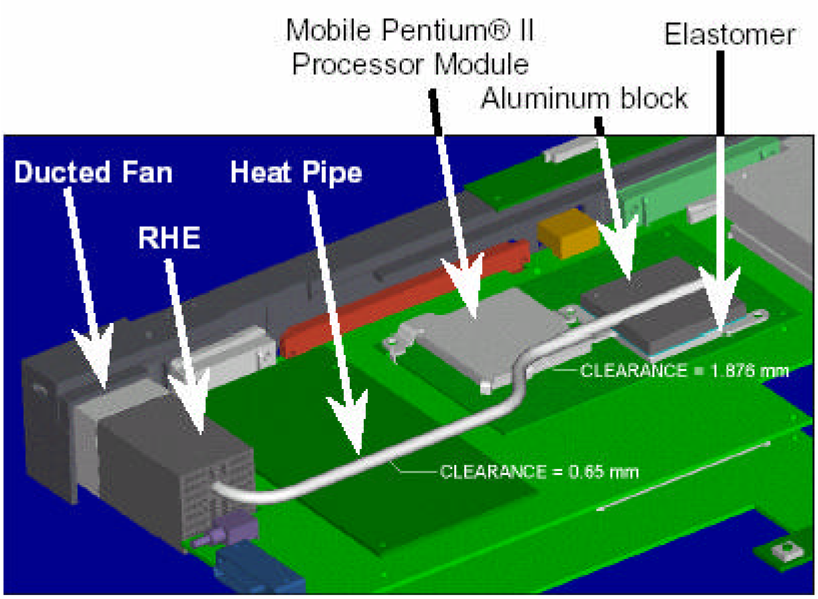
$$\Delta T_{Total} = \Delta T_{Block} + \Delta T_{Inter} + \Delta T_{HP} + \Delta T_{Conv} + \Delta T_{Fin} + \Delta T_{Air}$$

The thermal resistance of the sink to ambient is:

$$R_{s-a} = {\Delta T_{Total}}/{Q}$$

The above thermal resistance model can be easily used to determine thermal resistances for both natural and forced convection heat pipe heat sinks.

Typical passive cooling solutions in portable systems, involving the use of heat pipes, can handle about 8 W of power. In order to manage higher power dissipation levels, cooling solutions using a combination of heat pipes, heat sinks and fans have been proposed. Figure below shows a typical design for cooling higher than 12 W processors. In this design, a heat pipe is used to transport the heat from the processor to a highly optimized remote heat exchanger (RHE). A small fan blows air over the RHE and dissipates the heat to the ambient air outside the notebook chassis. The design shown in Figure below was proposed as a possible cooling solution for the mobile Pentium ® II processor.



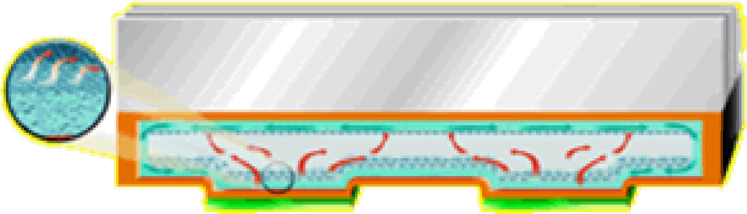
(Courtesy Thermacore Inc.)

Modern trends in heat pipe technology:

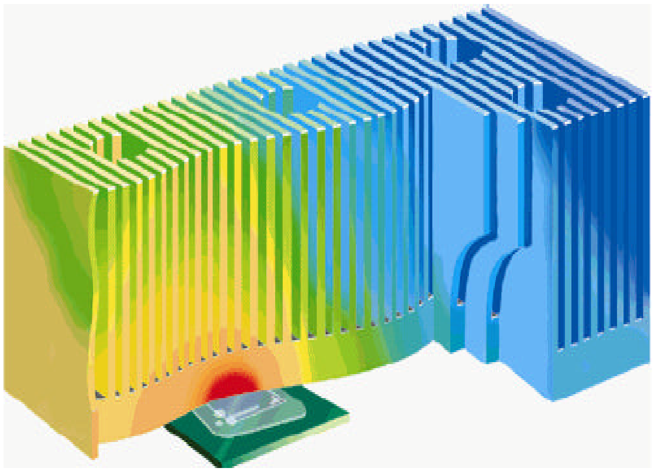
The following topics describe modern trends in heat pipe technology. There are few modified version of heat pipes than the original. Few of the examples are Vapor Chamber, Looped Heat Pipe, Embedded Heat Pipes etc.

Vapor Chamber:

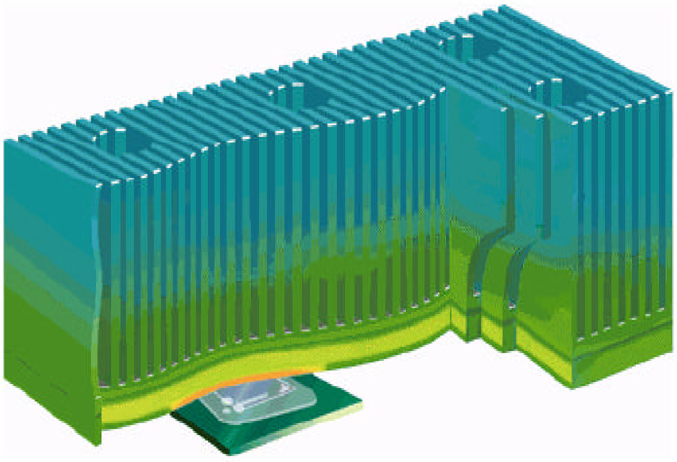
A vapor chamber is a vacuum vessel with a wick structure lining the inside walls that is saturated with a working fluid. As heat is applied, the fluid at that location immediately vaporizes and the vapor rushes to fill the vacuum. Wherever the vapor comes into contact with a cooler wall surface it will condense, releasing its latent heat of vaporization. The condensed fluid returns to the heat source via capillary action, ready to be vaporized again and repeat the cycle. The capillary action of the wick enables the vapor chamber to work in any orientation with respect to gravity. A vapor chamber heat sink consists of a vapor chamber integrated with cooling fins, pins, etc. Due to the way the vapor chamber operates, the heat source can be placed anywhere on the base without affecting its thermal resistance. In addition, there can be multiple heat sources dissipating the same or different amounts of power. The rate of fluid vaporization at each source will stabilize and the vapor chamber will be nearly isothermal.



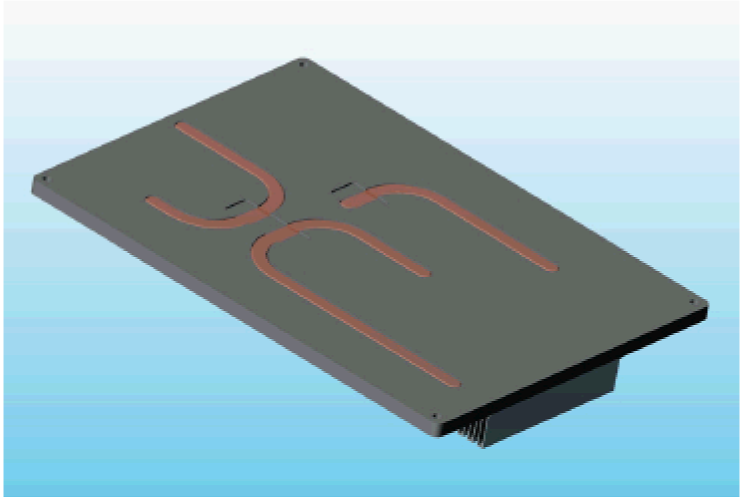
Without Vapor Chamber



With Vapor Chamber



Embedded Heat Pipes:



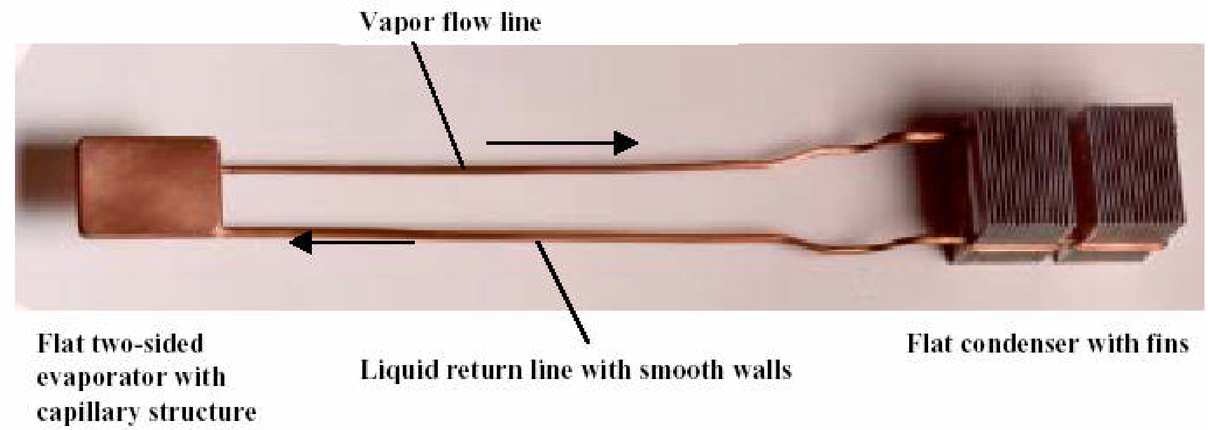
Embedding heat pipes into the heat sink is an effective cooling alternative to greatly enhance the performance of an existing heat sink with minimal design changes.

Embedded heat pipes extend the performance of an existing heat sink with minimal design changes, providing an effective alternative to other methods. For example, in the heat sink shown, heat pipes were embedded under a heat sink.

The heat pipes were 0.375" diameter flattened into grooves in the heat sink base with a thermal epoxy at the interface. This approach reduced the thermal resistance of the heat sink by 50%. Embedded heat pipes may provide the needed improvement in your existing heat sink.

Looped Heat Pipes:

Modern electronics applications though require transport of the dissipated thermal energy in horizontal orientation or horizontally oriented evaporator surfaces, and, typically, capillary structures in the evaporators for the heat transfer enhancement. Loop heat pipes generally can transport higher heat flow rates compared to conventional heat pipes, since there is high hydraulic resistance in LHP for the liquid returning the evaporator. However LHP are not restricted by the gravity aided liquid return conditions. Here, heat is applied to the flattened



evaporator and the working fluid vaporizes. It flows to the vapor line due to pressure difference and goes to condenser where heat is carried away by cooling fluid or fins with forced convection. Then the condensed fluid is then returned to the evaporator section by the liquid line.

Conclusion:

The use of heat pipes for the thermal management of desktop computers is an accepted and applied technology. The reliability and flexibility of the heat pipe has proven to be a valuable attribute that provides the system designer with increased layout possibilities and typically improved thermal performance. The recent manufacturing improvements have shown that the heat pipe can be fabricated with automated manufacturing processes that have lead to drastic increases in capacity and repeatability, while providing cost reductions. With the reductions in heat pipe prices, industries such as automotive and appliances are now considering heat pipes as a thermal management tool. Heat pipes offer an attractive approach to supplementing conventional heat sink solutions. They do not replace the conventional heat sink, but rather they provide a tool that allows the designer to reconfigure and or extend the performance of more conventional heat sinks such as extrusions or castings. When performance dictates, they allow the thermal designer to utilize a recently accepted heat sink alternative, the heat pipe heat sink assembly. The heat pipe heat sink assembly permits the designer to achieve what are otherwise unreachable thermal resistance levels via the efficient maximization of the heat sink surface area available for dissipation to the ambient air.

Nomenclature:

ABlock = Heat input area of evaporator block
AFin = Total surface area of fins
CP = Specific heat of air
EMI= Electromagnetic Interference
TAir = Thermal resistance of cooling air flow
TBlock = Thermal resistance of evaporator block
TConv = Thermal resistance due to convection
TFin = Thermal resistance due to fin efficiency
THP = Thermal resistance of heat pipe
TInter = Thermal resistance of evaporator block / heat pipe interface
h = Convection coefficient
Fin = Fin efficiency
kBlock = Thermal conductivity of evaporator block
kFin = Thermal conductivity of fins
LCond = Length of condenser (finned length)
LEff = Effective fin length
LEvap = Length of evaporator block / heat pipe interface
mFin = Fin factor for uniform cross-sectional area
m = Mass flow rate of cooling air
Q = Heat load to be dissipated
RAir = Thermal resistance of cooling air flow
RAxial = Thermal resistance along heat pipe
RBlock = Thermal resistance of evaporator block
RCond = Thermal resistance of the heat pipe condenser
RConv = Thermal resistance due to convection
REvap = Thermal resistance of the heat pipe evaporator
RFin = Thermal resistance due to fin efficiency
RHP = Thermal resistance of heat pipe
RHE = Remote Heat Exachanger
RInter = Thermal resistance of evaporator block / heat pipe interface
Rs-a = Thermal resistance of heat sink to ambient
tBlock = Thickness of the evaporator block
tFin = Thickness of the fins

References

1) Peterson, G.P. “*An Introduction to Heat Pipes Modeling, Testing, and Applications*”, John Wiley and Sons, Inc. 1994.
2) Dunn, P.D. and Reay D.A. “*Heat Pipes*” 4th edition, Pergamon. 1994.
3) "*Heat Pipe Application Guidelines*" Robert D. and Kevin G. Thermacore, Inc.
4) "*Heat Pipe Reliability Documentation*" Thermacore Inc. Nov 10, 1999.
5) "*Heat Pipes: The Silent Way to Manage Desktop Thermal Problems*” Jerome T., Robert D., Kevin G., THERMACORE, INC. Presented at I-THERM Conference May 1998 Seattle, WA.
6) “*Heat Pipes and Thermosyphons*”, Chang W.S., Gerner F.M., and Ravigururajan T.S., 1992, The Winter Annual Meetings Of ASME, HTD-Vol.221.
7) “*Advanced heat pipe thermal solutions for higher power notebook computers*” Andre A., Robert D., Kevin G., 1999.