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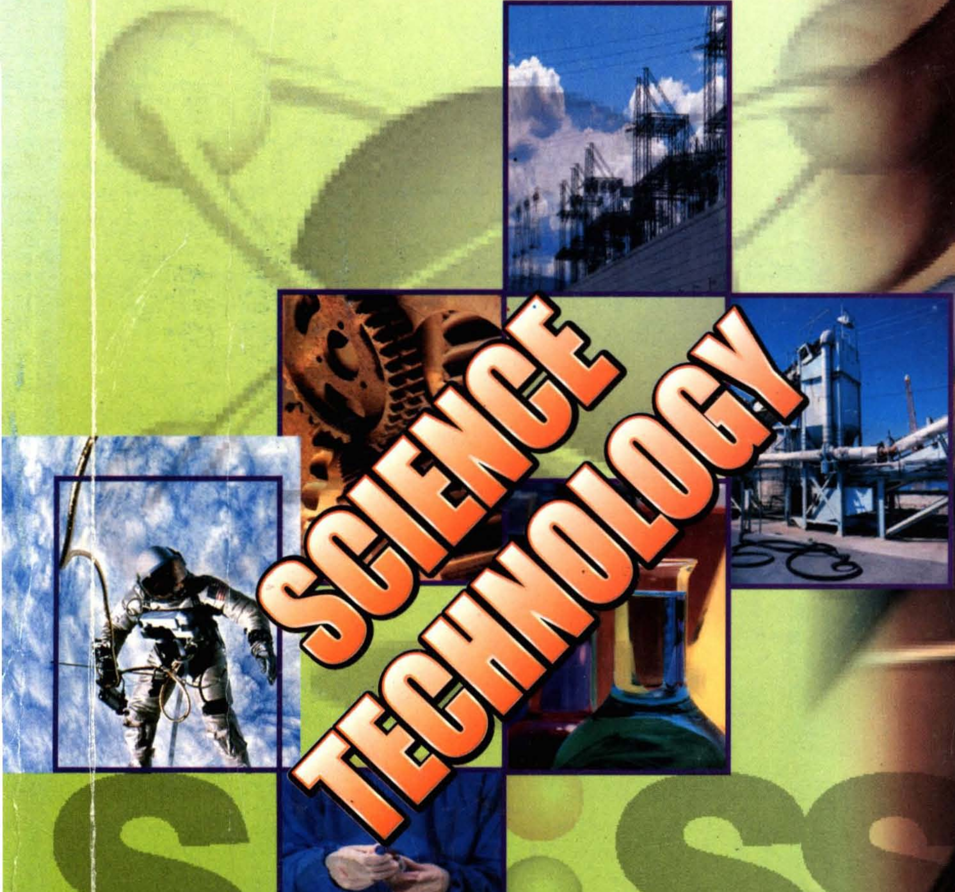

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Heat Pipe Technology for Electronic Cooling and Heat Recovery Systems

Ramadas Narayanan

ABSTRACT

Heat pipe is a two-phase heat transfer devices with extremely high effective thermal conductivity. They can be cylindrical or planar in structure. Heat pipes can be embedded in a metal cooling plate, which is attached to the heat source, and can also be assembled with fin stack for fluid heat transfer. Due to the high heat transport capacity, heat exchangers with heat pipes have become much smaller than traditional heat exchangers in handling high heat fluxes. With the working fluid in a heat pipe, heat can be absorbed on the evaporator region and transported to the condenser region where the vapor condenses releasing the heat to the cooling media. Heat pipe technology has found its increasing applications in Electronic Cooling and enhancing the thermal performance of Heat Recovery Systems in industrial sectors.

Keywords: *Heat pipe, heat pipe technology, electronic cooling, thermal conductivity, heat recovery system.*

Introduction

Heat pipe is a highly efficient two-phase heat transfer devices, with thermal conductivity ranging from 10 to 10, 00 times that of plain copper bar. They are often referred to as the "superconductors" of heat as they possess an extra ordinary heat transfer capacity and rate with almost no heat loss. It is a heat transfer mechanism that can transport large quantities of heat with a very small difference in tempereature between the hot and cold interfaces.

It consists of a vacuum-tight envelope, a wick and a working fluid. The heat pipe is filled with a small quantity of working fluid. When heat enters at the evaporator end, the fluid inside the heat pipe boils, and vapor is generated. The vapor travels to the condenser end, where the slightly lower temperatures cause the vapor to condense, and release the heat. The condensed fluid is then returned to the evaporator via the wick, where the process begins a new. This continuous cycle is capable of transferring large quantities of heat.

A heat pipe is a passive device, driven only by the heat that is transferred. No external energy source is required. This passive operation results in high reliability, long life, and consequently, low warranty costs.

R.S.Gaugler first suggested the idea of heat pipes in 1942. However, it was not until 1962, when G.M.Grover invented it that its remarkable properties were appreciated & serious development began.

All electronic components, from microprocessors to high-end power converters, generate heat and rejection of this heat is necessary for their optimum and reliable operation. As electronic design allows higher throughput in smaller packages, dissipating the heat load becomes a critical design factor. Many of today's electronic devices require cooling beyond the capability of standard metallic heat sinks. The heat pipe is meeting this need and is rapidly becoming a mainstream thermal management tool.

Heat pipe technology can be used to move heat from a heat source to a location within the automobile where enough air volume exists for adequate heat removal. Fins are stacked on the heat pipes to provide adequate surface area for heat dissipation to the air.

Heat pipes are more effective than solid conductors, and require only a temperature difference to operate. A variety of envelope materials, wicking materials, and working fluids, can be employed to best suit your particular application.

Heat Pipe Structure

A. Heat is absorbed in the evaporating section.

B. Fluid boils to vapor phase.

C. Heat is released from the upper part of cylinder to the environment; vapor condenses to liquid phase.

D. Liquid returns by gravity to the lower part of cylinder (evaporating section).

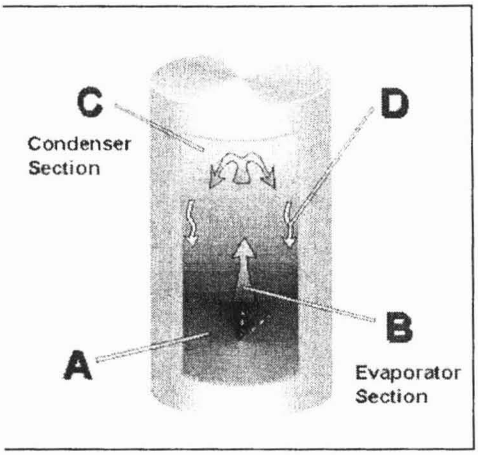

Fig. 1: A Traditional Heat Pipe is a Hollow Cylinder Filled with a Vaporizable Liquid

A heat pipe consists of three basic components:

1. Container
2. Wick or Capillary structure
3. Working fluid

The container is evaluated hollow tube made up of copper or steel and sealed at both ends. After the evacuation, the container is partially filled with working fluid. Some common working fluids are water, refrigerants, alcohol, etc. The inside wall of the container is limed with porous material or wick structure. The main purpose of wick is to generate capillary pressure to transport the working fluid from condenser to the evaporator.

Mechanism

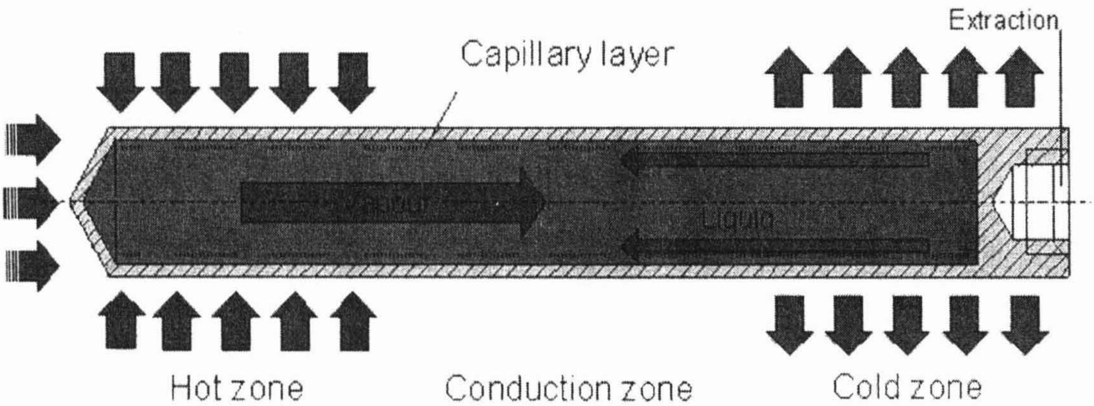

Fig. 2: Heat Transfer in Heat pipe

Heat pipes employ evaporative cooling to transfer thermal energy from one point to another by the evaporation and condensation of a working fluid. Heat pipes rely on a temperature difference between the ends of the pipe, and cannot lower temperatures at either end beyond the ambient temperature (hence they tend to equalise the temperature within the pipe).When one end of the heat pipe is heated the working fluid inside the pipe at that end evaporates and forms a vapour inside the cavity of the heat pipe. The latent heat of evaporation absorbed by the vaporisation of the working fluid proportionally reduces the temperature at the hot end of the pipe.

The vapour naturally disperses to an even density inside the heat pipe. When the vapour reaches the cooler end of the pipe, it condenses and releases its latent heat resulting in an increase in temperature at the cool end of the pipe.

This process creates a flow of vapour from the hot interface to the cold interface of the heat pipe. The condensed working fluid then flows back to the hot end of the pipe, either by force of gravity in the case of vertially oriented heat pipes, or through capillary action in the case of heat pipes containing wicks.In summary, inside a heat pipe "hot" vapor flows in one direction and condenses and cooler liquid flows in the other where it evaporates.

Heat Pipe Design

There are many factors to consider when designing a heat pipe: compatibility of materials, operating temperature range, diameter, power limitations, thermal resistances, and operating orientation. However, the design issues are reduced to two major considerations by limiting the selection to copper/water heat pipes for cooling electronics. These considerations are the amount of power the heat pipe is capable of carrying and its effective thermal resistance. These two major heat pipe design criteria are discussed below. The design considerations for the three basic components of a heat pipe are as follows.

Container

The function of the container is to isolate the working fluid from the outside environment. It has to therefore be leak-proof, maintain the pressure differential across its walls, and enable transfer of heat to take place from and into the working fluid. Selection of the container material depends on many factors. These are as follows:

- Compatibility (both with working fluid and external environment)
- Strength to weight ratio
- Thermal conductivity
- Ease of fabrication, including welding, machineability and ductility
- Porosity
- Wettability

A high strength to weight ratio is more important in spacecraft applications. The material should be non-porous to prevent the diffusion of vapor. A high thermal conductivity ensures minimum temperature drop between the heat source and the wick.

Working Fluid

A first consideration in the identification of a suitable working fluid is the operating vapor temperature range. Within the approximate temperature band, several possible working fluids may exist, and a variety of characteristics must be examined in order to determine the most acceptable of these fluids for the application considered. The prime requirements are:

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

The selection of the working fluid must also be based on thermodynamic considerations which are concerned with the various limitations to heat flow occurring within the heat pipe like, viscous, sonic, capillary, entrainment and nucleate boiling levels. In heat pipe design, a high value of surface tension is desirable in order to enable the heat pipe to operate against gravity and to generate a high capillary driving force. In addition to high surface tension, it is necessary for the working fluid to wet the wick and the container material i.e. contact angle should be zero or very small. The vapor pressure over the operating temperature range must be sufficiently great to avoid high vapor velocities, which tend to setup large temperature gradient and cause flow instabilities.

A high latent heat of vaporization is desirable in order to transfer large amounts of heat with minimum fluid flow, and hence to maintain low pressure drops within the heat pipe. The thermal conductivity of the working fluid should preferably be high in order to minimize the radial temperature gradient and to reduce the possibility of nucleate boiling at the wick or wall surface. Choosing fluids with low values of vapor and liquid viscosities will minimize the resistance to fluid flow.

Wick or Capillary Structure

It is a porous structure made of materials like steel, aluminum, nickel or copper in various ranges of pore sizes. They are fabricated using metal foams, and more particularly felts, the latter being more frequently used. By varying the pressure on the felt during assembly, various pore sizes can be produced. By incorporating removable metal mandrels, an arterial structure can also be molded in the felt.

Fibrous materials, like ceramics, have also been used widely. They generally have smaller pores. The main disadvantage of ceramic fibers is that, they have little stiffness and usually require a continuous support by a metal mesh. Thus while the fibre itself may be chemically compatible with the working fluids, the supporting materials may cause problems. More recently, interest has turned to carbon fibres as a wick material. Carbon fibre filaments have many fine longitudinal grooves on their surface, have high capillary pressures and are chemically stable. A number of heat pipes that have been successfully constructed using carbon fibre wicks seem to show a greater heat transport capability.

The prime purpose of the wick is to generate capillary pressure to transport the working fluid from the condenser to the evaporator. It must also be able to distribute the liquid around the evaporator section to any area where heat is likely to be received by the heat pipe. Often these two functions require wicks of different forms. The selection of the wick for a heat pipe depends on many factors, several of which are closely linked to the properties of the working fluid. The maximum capillary head generated by a wick increases with decrease in pore size. The wick permeability increases with increasing pore size. Another feature of the wick, which must be optimized, is its thickness. Increasing the wick thickness raises the heat transport capability of the heat pipe. The overall thermal resistance at the evaporator also depends on the conductivity of the working fluid in the wick. Other necessary properties of the wick are compatibility with the working fluid and wettability.

The most common types of wicks that are used are as follows:

Sintered Powder
This type of wick will provide high power handling, low temperature gradients and high capillary forces for anti-gravity applications. A complex sintered wick can have several vapor channels and small arteries to increase the liquid flow rate. Very tight bends in the heat pipe can be achieved with this type of structure.

Grooved Tube
The small capillary driving force generated by the axial grooves is adequate for low power heat pipes when operated horizontally, or with gravity assistance. The tube can be readily bent. When used in conjunction with screen mesh the performance can be considerably enhanced.

Screen Mesh
This type of wick is used in the majority of the products and provides readily variable characteristics in terms of power transport and orientation sensitivity, according to the number of layers and mesh counts used.

Heat Pipes for Electronic Cooling

All electronic components, from microprocessors to high-end power converters, generate heat and rejection of this heat is necessary for their optimum and reliable operation. As electronic design allows higher throughput in smaller packages, dissipating the heat load becomes a critical design factor. Many of today's electronic devices require cooling beyond the capability of standard metallic heat sinks. The heat pipe is meeting this need and is rapidly becoming a mainstream thermal management tool.

Perhaps the best way to demonstrate the heat pipes application to electronics cooling is to present a few of the more common examples. Currently, one of the highest volume applications for heat pipes is cooling the Pentium processors in notebook computers. Due to the limited space and power available in notebook computers, heat pipes are ideally suited for cooling the high power chips. Fan assisted heat sinks require electrical power and reduce battery life. Standard metallic heat sinks capable of dissipating the heat load are too large to be incorporated into the notebook package. Heat pipes, on the other hand, offer a high efficiency, passive, compact heat transfer solution. Three or four millimeter diameter heat pipes can effectively remove the high flux heat from the processor. The heat pipe spreads the heat load over a relatively large area heat sink, where the heat flux is so low that it can be effectively dissipated through the notebook case to ambient air. The heat sink can be the existing components of the notebook, from Electro-Magnetic Interference (EMI) shielding under the keypad to metal structural components. Various configurations of notebook heat pipe heat sinks are shown in Figure 3.

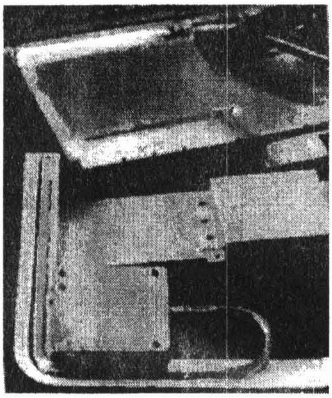

Fig. 3: Typical Notebook Heat Pipe Heat Sink

Typical thermal resistances for these applications at six to eight watt heat loads are 4 - 6°C/watt. High power mainframe, mini-mainframe, server and workstation chips may also employ heat pipe heat sinks. High-end chips dissipating up to 100 watts are outside the capabilities of conventional heat sinks. Heat pipes are used to transfer heat from the chip to a fin stack large enough to convect the heat to the supplied air stream. The heat pipe isothermalizes the fins eliminating the large conductive losses associated with standard sinks. The heat pipe heat sinks, shown in Figure 4, dissipate loads in the 75 to 100 watt range with resistances from 0.2 to 0.4°C/watt, depending on the available air flow.

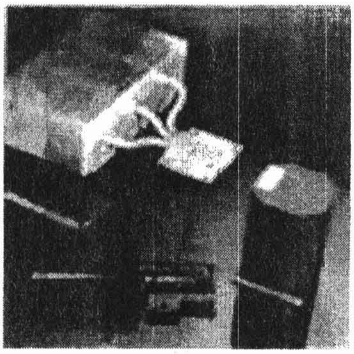

Fig.4: High End CPU Heat Pipe Heat Sink

Heat Pipes in Heat Exchangers and Industrial Processes

Hill (1993) studied supermarket air-conditioning systems equipped with heat pipe heat exchangers. Operation in four different climates was considered. The heat pipe heat exchangers were used to save refrigeration energy by reducing the humidity of the refrigerated spaces. Rosenfeld (1995) at Thermacore discussed the use of heat pipes in "porous media heat exchangers" for the cooling of high heat load optical components. A number of commercial manufacturers located in the US and Canada produce heat exchangers that use heat pipes. Heat pipe heat exchangers can be used as air pre-heaters for electric utility boilers, hydrocarbon processing industry furnaces, and gas-to-gas heat exchangers used in waste incinerators. The standard and custom industrial air-to-air heat pipe heat exchanger is used for electronic cabinets used in clean rooms, transmitter and telecommunication stations, and computers. Heat Pipe Technology can be used for internally finned refrigeration tubes to transport liquid in heat pipe heat exchangers for dehumidification and energy recovery. The modular heat pipe air heaters are used for energy recovery in hydrocarbon processing plants.

The utilization of heat pipe fin stack in the drying cycle of domestic appliances for heat recovery may lead to a significant energy saving in domestic sector.

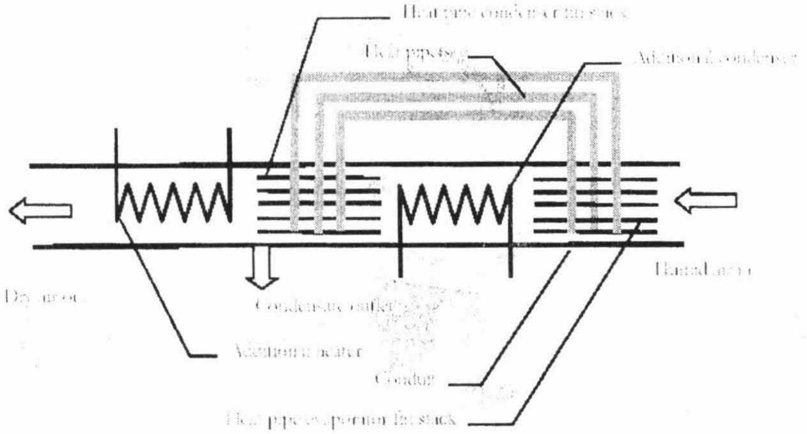

Fig. 5: Heat Recovery System using Heat Pipe Solution in Drying Cycle

The basic principle of the drying cycle system is that in a conduit, warm and humid air with 100% relative humidity is sucked in at the inlet, passes through the fin stack of the heat pipe unit, and further goes through the additional condenser. In the condensation section of the conduit, condensate is obtained on the fin surfaces and additional condenser surfaces and drained from the conduit. The humid air continuously flows through the other stack of the heat pipe unit and is warmed up by the heat transported from the upstream warmer humid air through the heat pipe unit. An additional heater is used to further heat up the air to certain temperature and humidity before the airflow returns into the drying process.

Conclusion

Heat pipes are excellent for transfer of high levels of heat output from confined areas. Once transferred from a confined area, heat can be effectively dissipated through a larger passive or active heat sink. Heat pipe has been, and is currently being, studied for a variety of applications, covering almost the entire spectrum of temperatures encountered in heat transfer processes. Heat pipes are used in a wide range of products like air-conditioners, refrigerators, heat exchangers, transistors, capacitors, etc. Heat pipes are also used in laptops to reduce the working temperature for better efficiency.

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RAMADAS NARAYANAN, School of Engineering, Curtin University of Technology, Sarawak.