HEAT PIPES AND ITS APPLICATION

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Abstract :

A heat pipe is a simple device that can quickly transfer heat from one point to another. They are often referred to as the "superconductors" of heat as they possess an extra ordinary heat transfer capacity & rate with almost no heat loss.

Introduction:

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

It consists of a sealed aluminum or copper container whose inner surfaces have a capillary wicking material. A heat pipe is similar to a thermosyphon. It differs from a thermosyphon by virtue of its ability to transport heat against gravity by an evapouration-condensation cycle with the help of porous capillaries that form the wick. The wick provides the capillary driving force to return the condensate to the evapourator. The quality and type of wick usually determines the performance of the heat pipe, for this is the heart of the product. Different types of wicks are used depending on the application for which the heat pipe is being used.

Design Considerations:

The three basic components of a heat pipe are:

1. The container
2. The working fluid
3. The wick or capillary structure

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

Most of the above are self-explanatory. A high strength to weight ratio is more important in spacecraft applications. The material should be non-porous to prevent the diffusion of vapour. 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 vapour 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
- Vapour pressure not too high or low over the operating temperature range
- High latent heat
- High thermal conductivity
- Low liquid and vapour 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 vapour pressure over the operating temperature range must be sufficiently great to avoid high vapour velocities, which tend to setup large temperature gradient and cause flow instabilities.

A high latent heat of vapourization 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. The resistance to fluid flow will be minimized by choosing fluids with low values of vapour and liquid viscosities.

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 moulded in the felt.

Fibrous materials, like ceramics, have also been used widely. They generally have smaller pores. The main disadvantage of ceramic fibres 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 evapourator. It must also be able to distribute the liquid around the evapourator 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. The heat transport capability of the heat pipe is raised by increasing the wick thickness. The overall thermal resistance at the evapourator 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 process will provide high power handling, low temperature gradients and high capillary forces for anti-gravity applications. 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.

Working Principle:

Inside the container is a liquid under its own pressure, that enters the pores of the capillary material, wetting all internal surfaces. Applying heat at any point along the surface of the heat pipe causes the liquid at that point to boil and enter a vapour state. When that happens, the liquid picks up the latent heat of vapourization. The gas, which then has a higher pressure, moves inside the sealed container to a colder location where it condenses. Thus, the gas gives up the latent heat of vapourization and moves heat from the input to the output end of the heat pipe.

Heat pipes have an effective thermal conductivity many thousands of times that of copper. The heat transfer or transport capacity of a heat pipe is specified by its " Axial Power Rating (APC)". It is the energy moving axially along the pipe. The larger the heat pipe diameter, greater is the APR. Similarly, longer the heat pipe lesser is the APR. Heat pipes can be built in almost any size and shape.

Applications:

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. Their application in the field of cryogenics is very significant, especially in the development of space technology. We shall now discuss a brief account of the various applications of heat pipe technology.

Space Technology:

The use of heat pipes has been mainly limited to this field of science until recently, due to cost effectiveness and complex wick construction of heat pipes. There are several applications of heat pipes in this field like

- Spacecraft temperature equalization

- Component cooling, temperature control and radiator design in satellites.
- Other applications include moderator cooling, removal of heat from the reactor at emitter temperature and elimination of troublesome thermal gradients along the emitter and collector in spacecrafts.

Heat pipes for Dehumidification and Air conditioning:

In air-conditioning system, the colder the air as it passes over the cooling coil (evapourator), the more the moisture is condensed out. The heat pipe is designed to have one section in the warm incoming stream and the other in the cold outgoing stream. By transferring heat from the warm return air to the cold supply air, the heat pipes create the double effect of pre-cooling the air before it goes to the evapourator and then re-heating it immediately.

Activated by temperature difference and therefore consuming no energy, the heat pipe, due to its pre-cooling effect, allows the evapourator coil to operate at a lower temperature, increasing the moisture removal capability of the air conditioning system by 50-100%. With lower relative humidity, indoor comfort can be achieved at higher thermostat settings, which results in net energy savings. Generally, for each 1° F rise in thermostat setting, there is a 7% savings in electricity cost. In addition, the pre-cooling effect of the heat pipe allows the use of a smaller compressor.

Laptop Heat Pipe Solution:

Heat pipe technology originally used for space applications has been applied it to laptop computer cooling. It is an ideal, cost effective solution. Its light weight (generally less than 40 grams), small, compact profile, and its passive operation, allow it to meet the demanding requirements of laptops.

For an 8 watt CPU with an environmental temperature no greater than 40°C it provides a 6.25°C/watt thermal resistance, allowing the processor to run at full speed under any environmental condition by keeping the case temperature at 90°C or less.

One end of the heat pipe is attached to the processor with a thin, clip-on mounting plate. The other is attached to the heat sink, in this case, a specially designed keyboard RF shield. This approach uses existing parts to minimize weight and complexity. The heat pipe could also be attached to other physical components suitable as a heat sink to dissipate heat.

Because there are no moving parts, there is no maintenance and nothing to break. Some are concerned about the possibility of the fluid leaking from the heat pipe into the electronics. The amount of fluid in a heat pipe of this diameter is less than 1cc. In a properly designed heat pipe, the water is totally contained within the capillary wick structure and is at less than 1 atmosphere of pressure. If the integrity of the heat pipe vessel were ever compromised, air would leak into the heat pipe instead of the water leaking out. Then the fluid would slowly vapourize as it reaches its atmospheric boiling point. A heat pipe's MTTF is estimated to be over 100,000 hours of use.

Thermal Control of Notebook and Mobile PC:

Heat pipes have proven to be the excepted means of providing thermal control in notebook and Mobile PCs systems. Heat pipes can move and dissipate CPU generate heat selectively throughout the system without affecting temperature sensitive components. Low wattage heat pipes (under 20 watts) have standardized input plates to the heat pipe. The connection to the heat exchanger via the heat pipe can have any number of configurations to accommodate component placement, multiple power ranges and fan options.

CPU Work Stations:

The heat pipe solution for thermal control at this level is a component and overall systems requirement. Not only do the heat pipes take on a different configuration with multiple heat pipes and cooling fins, but also airflow becomes the critical design factor. Heat pipes designed to move 75 watts are usually flat with fin stacks from three to six inches, in many cases with fins mounted on each side of the CPU input pad. Input pads are standard using stand-offs, transition sockets, and bolster plates on the bottom of the PC board. The spring clips used on the fan/heat sink combination won't work here. Airflow management is important in the overall efficiency of the heat pipe and should be calculated along with the intended heat pipe design.

Work Stations 75 to 100 Watts:

Thermal solutions are normally designed with multiple heat pipes, dedicated airflow and maximum input area. Fins stacks typically extend over both sides of the CPU. Input attachment to the CPU is with stand-offs, transition sockets or bolster plates.

500 MHz Operating Systems:

This group uses two thermal products, heat pipes to transfer the CPU heat (100 to 300 watts) and a second internal or external cooling source. Input power is generated from multiple CPUs and components with single or multiple heat pipes. Cooling temperatures on the output range from -0° C to - 40° C. This system requires thermal isolation because of dewpoint considerations.

Flexible Solutions:

Heat pipes are manufactured in a multitude of sizes and shapes. Unusual application geometry can be easily accommodated by the heat pipe's versatility to be shaped as a heat transport device. If some range of motion is required, heat pipes can even be made of flexible material.

Two of the most common are:

Constant Temperature: The heat pipe maintains a constant temperature or temperature range.

Diode: The heat pipe will allow heat transfer in only one direction.

Mega Flats :

Flat heat pipes are typically used for cooling printed circuit boards or for heat leveling to produce an isothermal plane. Mega flats are several flat heat pipes sandwiched together.

Some of the flat heat pipes manufactured are:

XY Mega Flats: Surface maintained within .01° F isothermal with concentrated load centres.

6" x 6" Mega Flat: Dissipated 850 watts from a printed circuit board.

Weight Reduction Mega Flats:

Standard - aluminum construction.

Lightweight - 1/2 the weight of aluminum.

Very light weight - 1/3 the weight of aluminum.

SEM C and SEM E Mega Flats in stock. Low and light weight coefficient of thermal expansion (CTE) Mega Flats - any CTE from 2 to 10. Alloy H: 70% more conductive than, or 40% less weight than copper clad invar.

Cost Effectiveness of Heat Pipes :

The cost of heat pipes designed for laptop use is very competitive compared to other alternatives. Cost is partially offset and justified by improved system reliability and the increased life of cooler running electronics. Heat pipes, in quantity, cost a few dollars each while an entire cooling system will cost between $5 - $10 in production quantities, depending on the final design. Standard design products are available to reduce cost even further. Heat pipe manufacture has been a difficult area to compete in. Simple in concept, but difficult to apply commercially, the heat pipe is a very elusive technology & holds the key to the future of heat transfer & its allied applications.

Conclusion:

The research is going on. Further invention of high conducting material will meet the demands of transferring heat at very in microelectronic and small-scale semiconductor devices to advanced space applications.