A Review Paper on Role of Heat Pipes in Cooling

vishnu Agarwal(1) ,Dr. Sudhir Jain(2), Keerti Vyas(3),Ginni Jain (4)

Phd scholar(1),Professor(2),M.tech scholar(3,(4)

CTAE(1)(2),GITS(3)(4)

vish_mech@rediffmail.com,kkvyas18@gmail.com,jain24.ginni@gmail.com

Abstract- this paper presents a review on applications of heat pipes in different fields along with a brief introduction of these. Here mainly 8 applications are described in different fields which shows that the application field of heat pipes is vast . Need of this review is to make one familiar with the technology of heat pipes used for heat control in different devices and fields.

keywords: heat pipes, fluid, cooling, heat sink etc.

I. INTRODUCTION

In this paper an introduction to heat pipes is given along with their structure and application in different fields. Need of this review is to introduce one with the technology of heat pipes.

Heat pipes or heat pin is a heat transfer device that combines the principal of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces. A typical heat pipe consists of a sealed pipe or tube made of a material that is compatible with the working fluid such as copper for water heat pipes, or aluminium for ammonia heat pipes. The heat pipe is partially filled with a working fluid and then sealed. The working fluid mass is chosen so that the heat pipe contains both vapour and liquid over the operating temperature range. For heat pipe to transfer heat , it must contain saturated liquid and its vapour(gas phase)[1]. The saturated liquid vaporizes and travels to the condenser, where it is cooled and turned back to a saturated liquid. In a standard heat pipe, the condensed liquid is returned to the evaporated using wick structure exerting a capillary action on liquid phase of the working fluid.

II. COMPONENTS OF A HEAT PIPE[2]

The three basic components of a heat pipe are:
A. The container
B. The working fluid
C. The Wick or Capillary Structure

A. The 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.

B. The 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
- wet ability 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 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. The resistance to fluid flow will be minimized by choosing fluids with low values of vapour and liquid viscosities.

iii) The Wick or Capillary Structure

It is a porous structure made of materials like steel, aluminium, nickel or copper in various ranges of pore sizes. 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. The heat transport capability of the heat pipe is raised by increasing the wick thickness. 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 wet ability.

Fig 1: Different capillary structures[1]

III. PRINCIPLE OF OPERATION

the heat pipe in its simplest configuration is a closed, evacuated cylindrical vessel with the internal walls lined with a capillary structure or wick that is saturated with a working fluid. Since the heat pipe is evacuated and then charged with the working fluid prior to being sealed, the internal pressure is set by the vapour pressure of the fluid.

As the heat input to the evaporator, liquid in the wick structure is vaporized, creating a pressure gradient in the vapour core. Such pressure gradient forces the vapour to flow along the pipe to the cooling region where it condenses releasing its latent heat of evaporation, which is rejected to the surrounding by a heat sink.

The liquid then returns to the evaporator region through the pores in the wick structure by the action of capillary pressure produced by the small pores of the wick structure. As a result, heat is absorbed at one end of the heat pipe and rejected to the other. The working fluid serves as the heat transport medium. The heat input region of the heat pipe is called evaporator, the cooling region is called condenser, and this is because the working fluid is being vaporized or condensed. In between the evaporator and condenser regions, there may be an adiabatic region.

IV. THE SPECIAL FEATURES OF HEAT PIPES

The heat pipe has its special features:

A. Very High Thermal Conductivity
B. Low Relative Weight
C. Reliable in Operation
D. Flexible
E. The Temperature Operating Range

A. Very High Thermal Conductivity

Heat pipe utilizes latent heat of evaporation of the working fluid to transfer heat from the evaporator to condenser of the heat pipe. This mode results a very high thermal conductivity. The effective thermal conductivity is several orders of magnitudes greater than that of the best solid conductor.

B. Low Relative Weight

The heat pipe is not a solid metal piece**.** The weight can be significantly reduced.

C. Reliable in Operation

Heat pipes do not have moving parts; they are extremely reliable. The main cause of failure is non-condensable gas generation in the heat pipe. By proper chosen of container and working fluid combination, this problem can be eliminated.

D. Flexible

The heat pipes can be made in various forms. Circular heat pipe is the most popular from, since it is easy fabrication and low cost. There exist flat plate and double casing heat pipes, rigid and flexible heat pipes, as well as large and micro heat pipes.

E. The Temperature Operating Range
Heat pipe can be designed to operate over a wide range of temperature from cryogenic applications using helium or nitrogen as the working fluid to high temperature applications using silver. The type of working fluid and the operating pressure inside the heat pipe depend on the operating temperature. The operating temperature, in general, should be above the triple point temperature and below the critical temperature of the working fluid. For example the triple point and the critical of water are, respectively, 0.01 ^{o}C and 374.1 ^{o}C. This is the reason that the recommended working temperature of water heat pipe is set between the two temperatures. One more factor should be considered is high saturation pressure at high operating temperature. For high saturation pressure, the thickness of the container must be large. This will result a large transverse thermal resistance due to large conduction thermal resistance across the container walls. In electronic cooling applications it is desirable to maintain junction temperature below 80 to 150 ^{o}C, copper-water heat pipe are typically used.

Table 1: fluids and their temperature range.[3]

Fluids	Temperature Range °C
Helium	-271 ---- -269
Nitrogen	-203 ---- -160
Ammonia	-78 ---- 100
Acetone	0 ---- 120
Methanol	10 ---- 130
Water	30 ---- 200
Mercury	250 ---- 650
Sodium	600 ---- 1200
Silver	1800 ---- 2300

V. APPLICATIONS OF HEAT PIPE FOR COOLING OF DIFFERENT SYSTEMS

Heat pipe heat sink has been frequently used to remove the heat from power transistors, Thyristors , and individual chips. Currently, a popular application to use heat pipes is cooling Intel's Pentium processors in notebook computers. Perhaps the best way to demonstrate the heat pipes application to electronics cooling is to present a few of the more common examples.

A. Cooling of Laptop Computer.

B. Cooling of High Power Electronics.

C. HEAT PIPES for Dehumidification and Heat Recovery.

D. Heat pipes used as a heat exchanger in stem condensation.

E. Cold energy storage for agricultural product.

F. Heat pipe and phase change material for cooling concentrated photovoltaic technology.

G. Large scale loop heat pipe for geothermal heat extraction.

H. Ultra large heat pipes for cooling the earth.

Now let's see these applications in detail:

A Heat pipes keep laptops cool

ICs in today's laptop computers generate about 50 W/cm^2 of heat. To prevent overheating, a fan, often a noisy one, blows heat down onto a copper heat sink on the bottom of the computer, which can really warm up the users lap.

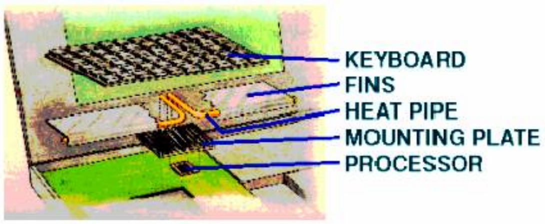


Fig 3: Heat pipes used in laptops.[4]

As chips get stacked and circuits are downsized, next-generation ICs might produce 100 W/cm^2, the heat levels produced by a light bulb and enough to damage the chips. This could cause some real discomfort. Heat pipes are one possible solution being studied at Sandia National Laboratory. Self-powered with no moving parts, they can direct heat to specific areas where it can be safely, and comfortably, dispersed. Heat pipes can also easily retrofit into existing laptop designs. In the heat pipe, heat converts liquid methanol into vapour, which travels the length of the pipe. At the cool end, which can be made cooler by using a small external fan if necessary, the vapour condenses to a liquid and is wicked back to the hot end. Wicks in this design are finely etched lines about as deep as fingerprints. Methanol travels up the wick using capillary action and defying gravity if necessary.

B. Cooling of High Power Electronics.
In addition, other high power electronics including Silicon Controlled Rectifiers (SCR's), Insulated

Gate Bipolar Transistors (IGBT's) and Thyristors , often utilize heat pipe heat sinks. Heat pipe, are capable of cooling several devices with total heat loads up to 5 kW. These heat sinks are also available in electrically isolated versions where the fin stack can be at ground potential with the evaporator operating at the device potentials of up to 10 kV. Typical thermal resistances for the high power heat sinks range from 0.05 to 0.1°C/watt. Again, the resistance is predominately controlled by the available fin volume and air flow.

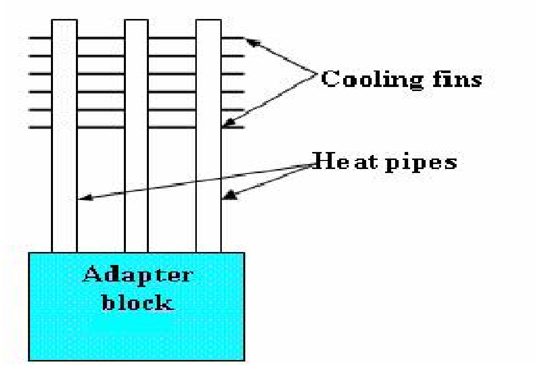


Fig 4:High power heat pipe heat sink assembly[4]

Fig 5:Heat pipe heat sink cools four IGBT's used as motor controllers in heavy industry[4]

Figure shows a large heat pipe unit that has several IGBTs mounted on it. The IGBTs are attached to a mounting plate and heat pipes embedded in the plate transports the heat to an air-cooled fin section. There are several different sized units like this being used in the field. Heat rejection from units like these is from 500 W to 8.3 kW with thermal resistance values from 0.004oC/W to 0.062oC/W. another example of some multi-kilowatt heat pipe units installed in a motor drive cabinet as shown in Figure

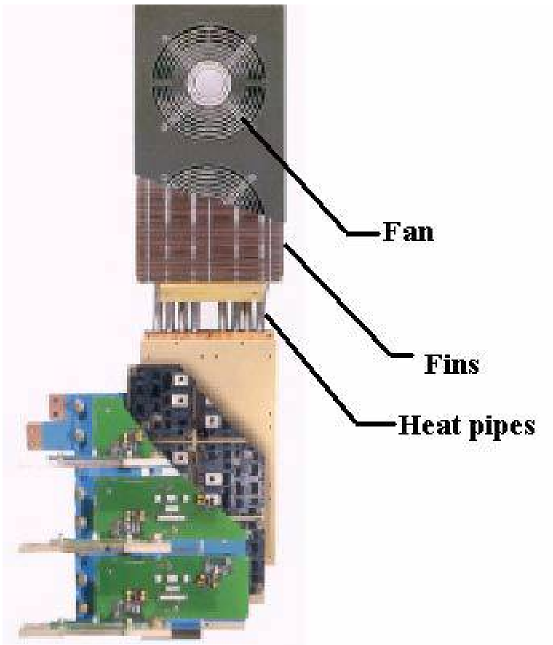


Fig 6:Multi-Kilowatt heat pipe assembly

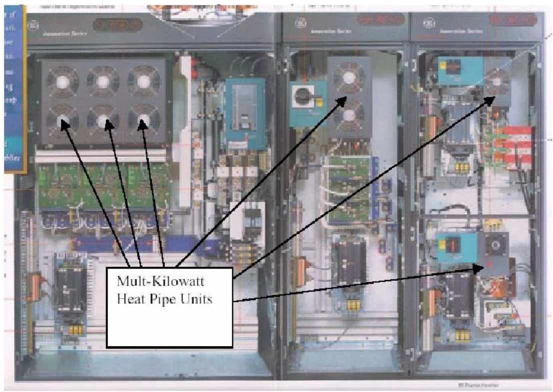


Fig 7:Multi-Kilowatt heat pipe units mounted in a motor drive cabinet.[5]

C. *Heat pipes for Dehumidification and Heat Recovery*

heat pipe is a passive two phase heat transfer device capable of transferring large quantities of heat with minimum temperature drop With increasing demands for energy efficient buildings, it is essential that energy is not wasted. Utilising a heat pipe, thermal energy can be recovered from warmer air and added to cooler air. In temperature climates this permits energy saving to be realised through preheating of the outside air. Conversely, in hot climates the savings are associated with pre-cooling of the outside air. HEAT PIPES can be arranged with airstreams side by side using tubes sloping down to the warmer air. Alternatively the air streams can be stacked with the warmer airstream at the bottom. This coupled with flexibility of sizing to suit the ductwork or air handling unit makes HEAT PIPES the ideal heat recovery solution.

D. *Heat pipes used as a heat exchanger in stem condensation*

L Vasiliev in 2005 (25) reviewed usage of Heat pipes in modern heat exchangers. He reported that,

heat pipes are very flexible systems with regard to effective thermal control. They can easily be implemented as heat exchangers inside sorption and vapour compression heat pumps, refrigerators and other types of heat transfer devices. Their heat transfer coefficient in the evaporator and condenser zones is 103-105 W/m 2K, heat pipe thermal resistance is 0.01 –0.03 K/W, therefore leading to smaller area and mass of heat exchangers. Miniature and micro heat pipes are welcomed for electronic components cooling and space two - phase thermal control systems. Thermal siphons ,Loop heat pipes, pulsating heat pipes and sorption heat pipes are the novelty for modern heat exchangers. Heat pipe air pre heaters are used in thermal power plants to preheat the secondary – primary air required for combustion of fuel in the boiler using the energy available in exhaust gases. Heat pipe solar collectors are promising for domestic use. But all these application are for energy recovery, air to air, air to gas exchanges and liquid to liquid only. Till now no application is made to condensate the steam using heat pipes .Heat pipe type Heat Exchanger for use in combination with a fast breeder reactor .HPHE is the recovery of heat from exhaust gases in industrial plants, heat pipe coolers for electronic cabinets.

E.Cold energy storage for agricultural products

Figure 8 shows the concept of using a heat pipe to collect cold energy in the winter season and storing underground to create a permafrost system for storage of agricultural products throughout the year. The whole cold energy system is passive, ie., there are no moving parts, there is no electrical consumption and it is reliable and maintenance free.

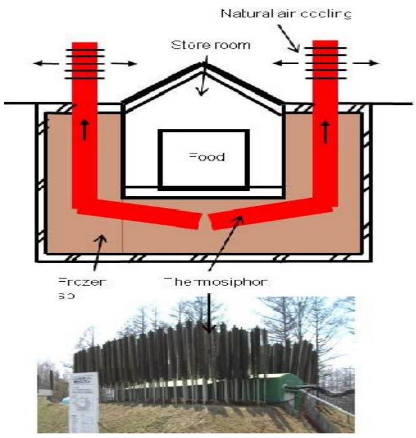
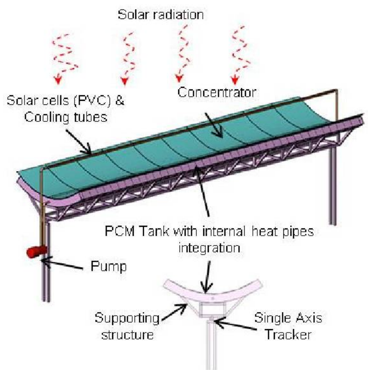


Fig 8:Cold energy storage.[6]

F. *Heat pipe and phase change material for cooling concentrated photovoltaic technology*

Concentrated photo-voltaic (CPV) technology offers incentives in terms of high conversion efficiency, semiconductor material savings and low unit electricity cost ($/W) as compared to flat-plate photo-voltaic modules. Thermal control of photo-voltaic cells is necessary to reduce temperature-related performance or efficiency drop and avoid material degradation. A 1oC cooling of photo-voltaic can help increase energy conversion efficiency in general by 0.5%. This section outlines the concepts of cooling solar CPV modules by means such as heat transport from cells to remote heat sinks by passive thermosiphons or active mechanical pumps, and diurnal storage of waste heat output by cells during the daytime in low-temperature phase change materials (PCMs) and night-time heat dissipation to ambient by means of natural convection and night sky radiation.



(a) Solar radiation day time

H. Large scale loop heat pipe for geothermal heat extraction

Figure 10 shows the concept of using large heat pipes for extraction of geothermal heat. Conventional heat pipes will not work by simply enlarging the heat pipe diameter and length, because the heat load will cause entrainment and flooding phenomena within the heat pipe.

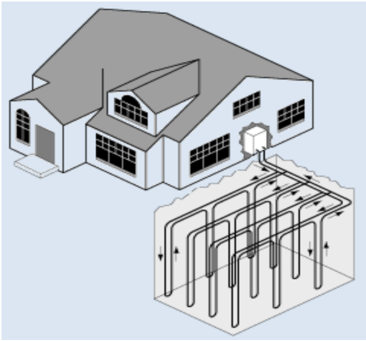


Fig 10: Ultra large Heat pipes.[6]

I. Ultra large heat pipes for cooling the earth

As mentioned before, global warming and protection of earth's environment have been hot topics of concern to all countries. The rise in CO2 production thus the rise in the earth's temperature may have been the cause of increased natural disasters in recent years. One idea to prevent the rise in the earth's temperature is to use an ultra-large scale heat pipe to dissipate the heat generated from people to outer space.

VI CONCLUSION

In this paper we have studied various applications of heat pipes and concluded that they are very efficient heat transport elements which can be described as light weight devices with high thermal conductance. They allow the transportation of high fluxes with small temperature difference with no change in operating temperature. They can operate at zero gravity environments. In addition there is no moving mechanical parts in heat pipes, and special sets of them can be used for temperature control, as thermal diodes and thermal switches. Heat pipe offer an attractive approach in supplementing conventional heat sink solutions for some applications .They can be used for wide variety of applications such as computer processor cooling, isothermal furnace liners, aerospace heat transfer,. Moreover, heat pipes can be built in different geometries and sizes.

REFRENCES

[1] Huber U, Stoeckli F, Houriet JP. A generalization of theDubinin–Radushkevich equation for the filing of heterogeneousmicropore systems in strongly activated carbons. J Colloid Interface Sci 1978;67(2):195–203.

[2] Passos FP. Etude des couples charbon actif/methanol et deleur application a la refrigerations solaire [Ph.D.] Lausanne: Ecole Polytechnique Federale de Lausanne; 1986.101p.

[3] MPE 635: Electronics Cooling.

[4] extraction of geothermal energy and electric power generation using a large scale heat pipe by shunji kusaba, Hirosi Suzuki , Kazuo Hirowatari, Masataka Mochizuki 3, Koichi Mashiko , Thang Nguyen, and Akbar Akbarzadeh .

[5] efficient design, operation, maintenance and management of cold storage dr. manoj kumar chourasia ISSN: 2076-9946, EISSN: 2076-9954.

[6] Retrofitting of power plant condensers with heat pipe heat exchanger : A case study T. Mallikharjuna Rao Central Power Research Institute, TRC, Koradi, Nagpur-441 111,INDIA

About Authors:

Mr Vishnu agarwal is a PhD research scholar in the department of renewable energy, CTAE Udaipur. He is M.E in thermal engineering from engineering college kota (UCE).He have more than 10 years of experience in teaching field .His area of interest is thermal and design .he is doing analysis of heat pipe in his PhD work. he guided many B.tech /M.tech projects.

Dr Sudhir Jain is a professor in the department of renewable energy in CTAE, Udaipur. He served more than 25 years in this field. He did his PhD from nether land, he suggest the way to utilize the waste water hyacinth. His area of research is renewable energy sources, and he guided many B.Tech/M.tech & PhD projects.

Keerti Vyas is a M.Tech, Research Scholar in the department of Electronics and Communication Engineering at Geetanjali Institute of Technical Studies, Udaipur. She has done B.Tech with honours from MLVTEC, Bhilwara. She has made project on image compression. Currently she is working in the field of VLSI Design. She has been an active member in organizing workshops in the college.. She has keen interest in research work related to Low Power VLSI.

Ginni Jain is a M.Tech, Research Scholar in the department of Electronics and Communication Engineering at Geetanjali Institute of Technical Studies, Udaipur. She has done B.Tech with honours from GITS, Udaipur. She has made projects on PLC SCADA and image processing. Currently she is working in the field of VLSI Design. She has been an active member in organizing workshop held in GITS, Udaipur,NWMM,11 on MSP430. She has keen interest in research work related to Low Power VLSI.