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A Review On Heat Transfer Study Approach Through Micro Heat Pipe Using Nano Fluids

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Abstract— Micro heat pipes are small and passive heat transfer devices. Research is going on in its applications ranging from using them in high powered electronic devices to using them during brain surgeries. A combination of silicon with many different liquids as working fluids is being investigated. This thesis investigates the fabrication of micro heat pipes arrays and the possibility ofusing mercury as one of the working fluids. Water was also tried on some of them. A new sealing technique was used to seal the micro heat pipes filled with mercury. Tests were carried out on these charged devices and silicon dummies under an infra-red camera. The results of the charged devices were compared with silicon dummy to check their working feasibility. The micro fabrication, charging, sealing and testing procedures are discussed in the following work. The results obtained from the tests conducted are also presented. Heat pipe is device working on two phase change of working fluid inside. This phase changeof working fluid lead to increasing heat transport efficiency of heat pipe. The basic heat pipe working position is vertical position, when the heat pipe can transport maximal heat flow from evaporator to condensates. This article deals about wick heat pipe construction and propose device to identify thermal performance. The result of article is comparison of thermal performance transported by heat pipe from working positions.

Keywords: Heat Transfer, Micro Fabrication, Heat pipe, Mercury, Heat flow

I. INTRODUCTION

HEAT PIPE MATERIALS AND WORKING FLUIDS

Heat pipes have an envelope, a wick, and a working fluid. Heat pipes are designed for very long-term operation with no maintenance, so the heat pipe wall and wick must be compatible with the working fluid. Some material/working fluids pairs that appear to be compatible are not. For example, water in an aluminium envelope will develop large amounts non-condensable gas over a few hours or days, preventing normal operation of the heat pipe. Since heat pipes were rediscovered by George Grover in 1963, extensive life tests have been conducted to determine compatible envelope/fluid pairs, some going on for decades. In a heatpipe life test, heat pipes are operated for long periods of time, and monitored for problems such as non-condensable gas generation, material transport, and corrosion.

Table 1 Heat pipe working fluid

S.NO	MEDIUM	MELTING POINT	BOILING POINT	MELTING RANGE
1	HELIUM	-271	-261	-271 to -261
2	NITROGEN	-210	-196	-203 to -160s
3	AMMONIA	-78	-33	-60 to 100
4	ACETON	-95	-57	1 to 120
5	METHANOL	-98	-64	10 to 130
6	WATER	0	100	30 to 200
7	MERCURY	-39	361	650

II. The Most Commonly Used Envelope (and wick)/Fluid Pairs Include:

- ❖ Copper envelope with water working fluid for electronics cooling. This is by far the most common type of heat pipe.
- ❖ Copper or steel envelope with refrigerant R134a working fluid for energy recovery in HVAC systems.
- ❖ Aluminum envelope with ammonia working

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fluid for spacecraft thermal control.

- Superalloy envelope with alkali metal (cesium, potassium, sodium) working fluid for high temperature heat pipes, most commonly used for calibrating primary temperature measurement devices.
- Other pairs include stainless steel envelopes with nitrogen, oxygen, neon, hydrogen, or helium working fluids at temperatures below 100 K, copper/methanol heat pipes for electronics cooling when the heat pipe must operate below the water range, aluminium/ethane heat pipes for spacecraft thermal control in environments when ammonia can freeze , and refractory metal envelope/lithium working fluid for high temperature (above 1,050 °C (1,920 °F)) applications.

Table 2 heat pipe working fluid chemical properties

S.NO	CONTAINER MATERIAL	WORKING FLUIDS	TEMPERATURE RANGE
1	COPPER	WATER	52 TO 277
2	ALUMINIUM	LIQUID NITROGEN	-213 TO -173
3	STAINLESS STEEL	AMMONIA	-73 TO 27
4	NICKEL	AMMONIA	-73 TO 27
5	GLASS	ACETON	52 TO 127
6	BRASS	ACETON	52 TO 127
7	TUNGSTEN	LITHIUM	1027 TO 1627
8	CARBONSTEEL	AMMONIA	-73 TO 23
9	IRON	FREON	-43 TO 27
10	NIOBIOM	SODIUM	627 TO 1227

III.DIFFERENT TYPES OF HEAT PIPES

- In addition to standard, Constant Conductance Heat Pipes (CCHPs), there are a number of other types of heat pipes, including:
- Vapor Chambers (planar heat pipes), which are used for heat flux transformation, and is thermalization of surfaces
- Variable Conductance Heat Pipes (VCHPs), which use a Non- Condensable Gas (NCG) to change the heat pipe effective thermal conductivity as power or the heat sink conditions change
- Pressure Controlled Heat Pipes (PCHPs), which are a VCHP where the volume of the reservoir, or the NCG mass can be changed, to give more precise temperature control
- Diode Heat Pipes, which have a high thermal conductivity in the forward direction, and a low thermal conductivity in the reverse direction
- Thermosyphons, which are heat pipes where the liquid is returned to the evaporator by gravitational/acceleration forces,
- Rotating heat pipes, where the liquid is returned to the evaporator by centrifugal forces

1)Vapor Chamber or Flat Heat Pipes

Thin planar heat pipes (heat spreaders) have the same primary components as tubular heat pipes: a hermetically sealed hollow vessel, a working fluid, and a closed-loop capillary recirculation system. In addition, an internal support structure or a series of posts are generally used in a vapor chamber to accommodate clamping pressures sometimes up to 90 PSI. This helps prevent collapse of the flat top and bottom when the pressure is applied. There are two main applications for vapor chambers. First, they are used when high powers and heat fluxes are applied to a relatively small evaporator. Heat input to the evaporator vaporizes liquid, which flows in two dimensions to the condenser surfaces. After the vapor condenses on the condenser surfaces, capillary forces in the wick return the condensate to the evaporator. Note that most vapor chambers are insensitive to gravity, and will still operate when inverted, with the evaporator above the condenser. In this application, the vapor chamber acts as a heat flux transformer, cooling a high heat flux from an electronic chip or laser diode, and transforming it to a lower heat flux that can be removed by natural or forced convection. With special evaporator wicks, vapor chambers can remove 2000 Wover 4 cm^2, or 700 W over 1 cm^2. Second, compared to a one-dimensional tubular heat pipe, the width of a two-dimensional heat pipe allows an adequate cross section for heat flow even with a very thin device. These thin planar heat pipes are finding their way into “height sensitive” applications, such as notebook computers and surface mount circuit board cores. It is possible to produce flat heat pipes as thin as 1.0 mm (slightly thicker than a 0.76 mmcredit card).

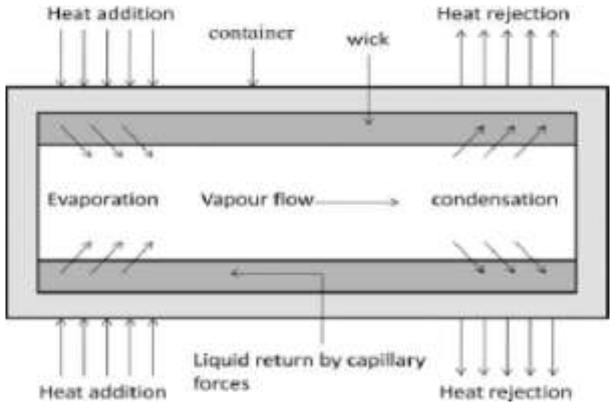


Figure 2 flat heat pipe

2) Variable Conductance Heat Pipes (VCHPs)

Standard heat pipes are constant conductance devices, where the heatpipe operating temperature is set by the source and sink temperatures, the thermal resistances from the source to the heat pipe, and the thermal resistances from the heat pipe to the sink. In these heat pipes, the temperature drops linearly as the power or condenser temperature is reduced. For some applications, such as satellite or research balloon thermal control, the electronics will be overcooled at low powers, or at the low sink temperatures. Variable Conductance Heat Pipes (VCHPs) are used to passively maintain the temperature of the electronics being cooled as power and sink conditions change. Variable conductance heat pipes have two additions compared to a standard heat pipe: 1. a reservoir, and 2. a non-condensable gas (NCG) added to the heat pipe, in addition to the working fluid; see the picture.

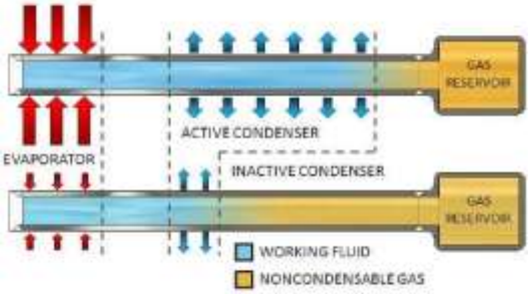


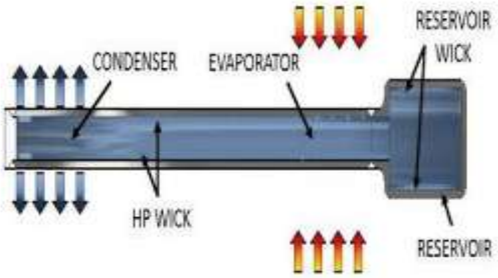
Figure 3 variable conductance heat pipe

This non-condensable gas is typically argon for standard Variable conductance heat pipes, and helium for thermosyphons. When the heat pipe is not operating, the non-condensablegas and working fluid vapor are mixed throughout the heat pipe vapor space. When the variable conductance heat pipe is operating, the non- condensable gas is swept toward the condenser end of the heat pipe bythe flow of the working fluid vapor. Most of the non-condensable gas is located in the reservoir, while the remainder blocks a portion of the heat pipe condenser.

The variable conductance heat pipe works by varying the active length of the condenser. When the power or heat sink temperature is increased, the heat pipe vapor temperature and pressure increase. The increased vapor pressure forces more of the non-condensable gas into the reservoir, increasing the active condenser length and the heat pipe conductance. Conversely, when the power or heat sink temperature is decreased, the heat pipe vapor temperature and pressure decrease, and the non-condensable gas expands, reducing the active condenser length and heat pipe conductance. The addition of a small heater on the reservoir, with the power controlled by the evaporator temperature, will allow thermal control of roughly ±1-2 °C. In one example, the evaporator temperature was maintained in a ±1.65 °C control band, as power was varied from 72 to 150 W, and heat sink temperature varied from +15 °C to -65 °C.Pressure controlled heat pipes (PCHPs) can be used when tighter temperature control is required. In a pressure-controlled heat pipe, the evaporator temperature is used to either vary the reservoir volume, or the amount of non-condensable gas in the heat pipe. Pressure controlled heat pipes have shown milli-Kelvin temperature control.

3)Diode Heat Pipes

Conventional heat pipes transfer heat in either direction, from the hotter to the colder end of the heat pipe. Several different heat pipes act as a thermal diode, transferring heat in one direction, while acting as an insulator in the other. Thermosyphons, which only transfer heat from the bottom to the top of the thermosyphon, where the condensate returns by gravity. When the thermosyphon is heated at the top, there is no liquid available to evaporate. Rotating heat pipes, where the heat pipe is shaped so that liquid can only travel by centrifugal forces from the nominal evaporator to the nominal condenser. Again, no liquid is available when the nominal condenser is heated.



Figures 4 diode heat pipe

4) Vapor Trap Diode Heat Pipes.

A vapor trap diode is fabricated in a similar fashion to a variable conductance heat pipe, with a gas reservoir at the end of the condenser. During fabrication, the heat pipe is charged with the working fluid and a controlled amount of a non-condensable gas (NCG). During normal operation, the flow of the working fluid vapor from the evaporator to the condenser sweeps the non-condensable gas into the reservoir, where it doesn't interfere with the normal heat pipe operation. When the nominal condenser is heated, the vapor flow is from the nominal condenser to the nominal evaporator. The non-condensable gas is dragged along with the flowing vapor, completely blocking the nominal evaporator, and greatly increasing the thermal resistivity of the heat pipe. In general, there is some heat transfer to the nominal adiabatic section. Heat is then conducted through the heat pipe walls to the evaporator. In one example, a vapor trap diode carried 95 W in the forward direction, and only 4.3 W in the reverse direction.

5)Liquid Trap Diode Heat Pipes

A liquid trap diode has a wicked reservoir at the evaporator end of the heat pipe, with a separate wick that is not in communication with the wick in the remainder of the heat pipe. During normal operation, the evaporator and reservoir are heated. The vapor flows to the condenser, and liquid returns to the evaporator by capillary forces in the wick. The reservoir eventually dries out, since there is no method for returning liquid. When the nominal condenser is heated, liquid condenses in the evaporator and the reservoir. While the liquid can return to the nominal condenser from the nominal evaporator, the liquid in the reservoir is trapped, since the reservoir wick is not connected. Eventually, all of the liquid is trapped in the reservoir, and the heat pipe ceases operation.

6) Loop heat Pipe

A loop heat pipe (LHP) is a passive two-phase transfer device related to the heat pipe. It can carry higher power over longer distances by having co-current liquid and vapor flow, in contrast to the counter-current flow allows the wick in a loop heat pipe to be required only in the evaporator and compensation chamber. Micro loop heat pipes have been developedand successfully employed in a wide sphere of applications both on the ground and in space.

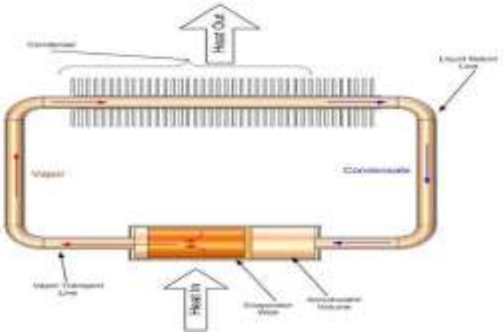


Figure 5 loop heat pipe

7) Oscillating or Pulsating Heat Pipe

An oscillating heat pipe, also known as a pulsating heat pipe, is only partially filled with liquid working fluid. The pipe is arranged in a serpentine pattern in which freely moving liquid and vapor segments alternate. Oscillation takes place in the working fluid; the pipe remains motionless.

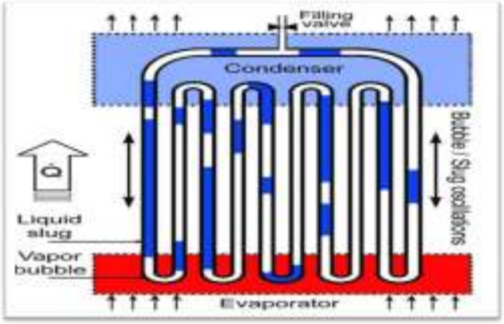


Figure 6 pulsating heat pipe

8)THERMOSYPHONS

- Most heat pipes use a wick to return the liquid from the condenser to the evaporator, allowing the heat pipe to operate in any orientation. The liquid is sucked up back to the evaporator by capillary action, similar to the way that a sponge sucks up water when an edge is placed in contact with a pool of water. However, the maximum adverse elevation (evaporator over condenser) is relatively small, on the order of 25 cm long for a typical water heat pipe.
- If, however, the evaporator is located below the condenser, the liquid can drain back by gravity instead of requiring a wick, and the distance between the two can be much longer. Such a gravity aided heat pipe is known as a thermosyphon.
- In a thermosyphon, liquid working fluid is vaporized by a heat suppliedto the evaporator at the bottom of the heat pipe. The vapor travels to the condenser at the top of the heat pipe, where it condenses. The liquid then drains back to the bottom of the heat pipe by gravity, and the cycle repeats. Thermosyphons are diode heat pipes; when heat is applied to the condenser end, there is no condensate available, and hence no way to form vapor and transfer heat to the evaporator.
- While a typical terrestrial water heat pipe is less than 30 cm long, thermosyphons are often several meters long. As discussed below, the thermosyphons used to cool the Alaska pipe line were roughly 11 to 12 m long. Even longer thermosyphons have been proposed for the extraction of geothermal energy. For example, Storch et al. fabricated a 53 mm I.D., 92 m long propane thermosyphon that carried roughly 6 kW of heat.

9) HEAT TRANSFER

- A heat sink (aluminum) with heat pipes (copper) Heat pipes employ phase change to transfer thermal energy from one point to another by the vaporization and condensation of a working fluid or coolant. Heat pipes rely on a temperature difference between the ends of the pipe, and cannot lower temperatures at either end below the ambient temperature (hence they tend to equalize the temperature within the pipe).
- When one end of the heat pipe is heated, the working fluid inside the pipeat that end vaporizes and increases the vapor pressure inside the cavity of the heat pipe. The latent heat of vaporization absorbed by the working fluid reduces the temperature at the hot end of the pipe.
- The vapor pressure over the hot liquid working fluid at the hot end of the pipe is higher than the equilibrium vapor pressure over the condensing working fluid at the cooler end of the pipe, and this pressure difference drives a rapid mass transfer to the condensing end where the excess vapor condenses, releases its latent heat, and warms the cool end of the pipe. Non-condensing gases (caused by contamination for instance) in the vapor impede the gas flow and reduce the effectiveness of the heat pipe, particularly at low temperatures, where vapor pressures are low. The speed of molecules in a gas is approximately the speed of sound, and in the absence of non condensing gases (i.e., if there is only a gas phase present) this is the upper limit to the velocity with which they could travel in the heat pipe. In practice, the speed of the vapor through the heat pipe is limited by the rate of condensation at the cold end and far lower than the molecular speed. Note/explanation: The condensation rate is very close to the sticking coefficient times the molecular speed times the gas density, if the condensing surface is very cold. However, if the surface is close to the temperature of the gas, the evaporation caused by the finite temperature of the surface largely cancels this heat flux. If the temperature difference is more than some tens of degrees, the vaporization from the surface is typically

negligible, as can be assessed from the vapor pressure curves. In most cases, with very efficient heat transport through the gas, it is very challenging to maintain such significant temperature differences between the gas and the condensing surface. Moreover, this temperature differences of course corresponds to a large effective thermal resistance by itself. The bottleneck is often less severe at the heat source, as the gas densities are higher there, corresponding to higher maximum heat fluxes.

- The condensed working fluid then flows back to the hot end of the pipe. In the case of vertically oriented heat pipes the fluid may be moved by the force of gravity. In the case of heat pipes containing wicks, the fluid is returned by Capillary action.
- When making heat pipes, there is no need to create a vacuum in the pipe. One simply boils the working fluid in the heat pipe until the resulting vapor has purged the non-condensing gases from the pipe, and then seals the end.
- An interesting property of heat pipes is the temperature range over which they are effective. Initially, it might be suspected that a water-charged heat pipe only works when the hot end reaches the boiling point (100 °C, 212 °F, at normal atmospheric pressure) and steam is transferred to the cold end. However, the boiling point of water depends on the absolute pressure inside the pipe. In an evacuated pipe, water vaporizes from its triple point (0.01 °C, 32 °F) to its critical point (374 °C; 705 °F), as long as the heat pipe contains both liquid and vapor. Thus, a heat pipe can operate at hot-end temperatures as low as just slightly warmer than the melting point of the working fluid, although the maximum rate of heat transfer is low at temperatures below 25 °C (77 °F). Similarly, a heat pipewith water as a working fluid can work well above the atmospheric boiling point (100 °C, 212 °F). The maximum temperature for long term water heat pipes is 270 °C (518 °F), with heat pipes operating up to300 °C (572 °F) for short term tests.
- The main reason for the effectiveness of heat pipes is the vaporizationand condensation of the working fluid. The heat of vaporization greatly exceeds the specific heat capacity. Using water as an example, the energy needed to evaporate one gram of water is 540 times the amount of energy needed to raise the temperature of that same one gram of water by 1 °C. Almost all of that energy is rapidly transferred to the "cold" end when the fluid condenses there, making a very effective heat transfer system with no moving parts.

10) Application of Heat Pipe:

- Heat pipe are mainly used in desktop, CPU, refrigerator and other electronic components etc...,
- Thermal based power plant heat pipe is used cooling system for flue gas.
- Heat pipe is used as heat spreaders to avoid hotspots, a major issue in electrical industry is direct wire assembly compatible with electronic fabrication.

IV. LITERATURE REVIEW

Many researchers have presented the heat transfer characteristics of heat pipe using nanofluids. The nano meter sized particles have great potential in improving heat transfer of base fluids. The properties of nano particle of size lesser than 100 nm are different from conventional fluids and result show that there is an improvement in heat transfer.

Seok Hwan, Gunn hwang (2016) reported that operating temperature is 60- 90*c micro heat pipe is widely used in integrated electronics units as a cooling module to improve stability in operation and longtime of system. Working fluid is pure water container material oxygen free copper, filling ratio of working fluid is 20%

Fabian korn (2009) department of energy science, Lund university, swedon reported that complex heat transfer problem in heat pipe by possible calculating of operating temperature is 0 to 100*c. working fluid is ammonia, material is aluminum, steel, nickel.

Ramzi bey-oueslati (2011) said that heat pipe is used as heat spreaders to avoid hotspots, a major issue in electrical industry is direct wire assembly compatible with electronic fabrication.

Rojionium, Frederick (2013) department of nuclear engineering said that loop heat pipe with coherent micron porous evaporative wick is used to remove the heat and it achieve high heat removal capability material is copper working fluid is water.

CONSOL Inc. Research and development said that thermal based power plant heat pipe is used cooling system for flue gas. Xuan and Lihave studied the thermal conductivity and convective heat transfer of nanomaterials as substitutes to water and ethylene glycol.

Lin et al. have presented the experimental results of a two-phase heat transfer of R141b refrigerant in a 1 mm diameter tubulin et al. have developed a miniature heat pipe for heat removal of high heat flux electronics devices. Thermal performance of a solar cooking system using vacuum tube collectors with heat pipes and a refrigerant as working fluid has been experimentally investigated by Esen.Song et al**.** have experimentally investigated the heat transfer performance of axially rotating heat pipes by the effects of the rotational speed, heat pipe geometry, and working fluid loading under steady state.

Xuan et al. have investigated the effects of the different heat fluxes, orientations and amount of the working fluid on the performance of a flat plate heat pipe. Wen and Dinghave experimentally investigated the convective heat transfer of nanofluids in a copper tube at the entrance region under laminar flow conditions. Zhouhas investigated the improvement in heat transfer characteristics of copper nanofluids with and without acoustic cavitation‟s.

Bang and Changhave studied the boiling heat transfer characteristics of water with Al2O3 nanoparticles suspended by the effects of different volume concentrations of nanoparticles. The application of heat pipes in modern heat exchangers and the micro and miniature heat pipes used in cooling of electronic components has been studied.

Huang et al. have evaluated the performance of a heat pipe in the solar- assisted heat pump water heater system. Lin et al. have simulated numerically a heat pipe heat exchanger integrated with the dehumidification process and Kleinstreuerhave proposed the steady laminar flow of liquid nanofluids in micro channels.

Liu et al. have experimentally investigated the effects of thermal conductivity of nanofluids, ethylene glycol and synthetic engine oil on the multiwall carbon

nanotubes. The convective heat transfer coefficient of nanofluids has been investigated under laminar flow in a horizontal tube heat exchanger by Yang et al.

Zenial Heirs et al**.** investigated the circular tube with the laminar flow convective heat transfer of oxide nanofluids under constant wall temperature boundary condition. Ang and Choihave numerically investigated the heat transfer characteristics of micro channel of heat sink with nanobuds‟ et al. have proposed the study of the heat and mass transfer properties of HFC134a gas hydrate in nano-copper suspension.

Palm et al. have numerically investigated a typical radial flow cooling system, an improvement in heat transfer characteristics of coolants with suspended metallic nanoparticles. Ang et al. have experimentally investigated on the heat transfer characteristics of heat pipe with silver nanofluid. Ding et al.have proposed a study on the heat transfer characteristics of aqueous suspensions of carbon nanotubes in pressure-driven laminar pipe flows of nanofluids. The effects of the length of the evaporator and vapor temperature on the critical values of the upper and lower boundaries of loop heat pipe were considered by Liu et al.

Vlassov et al.have investigated the characteristics of a heat pipe radiator assembly for space application filled with ammonia or acetone. He et al. have conducted study on the heat transfer and flow characteristics of aqueous suspensions of TiO2 nanoparticles flowing upward through a vertical pipe.

Nguyen et al.have experimentally investigated the heat transfer enhancement of an Al2O3–water nanofluid for cooling of electronic components.

Trickeryand Wongwises summarized the recent developments in research on the heat transfer characteristics of nano fluids. The presence of suspended nanoparticles enhances the heat transfer characteristics of conventional fluids.

Chein and Chuanghave studied the micro channel heat sink performance using nanofluids and compared the theoretical results with the measured data.

Mansour et al. have found the effect of uncertainties in physical properties on forced convection heat transfer with nanofluids.

V. EXISTING HEAT PIPE

Heat pipe discuss here different energy conservation as different energy conservation and renewable energy-based system using heat pipes as thermal control element have been discussed. Heat pipes provide two-phase reliable heat transfer system with passive operation and high effectiveness for these applications. Energy conservation system for data center cooling, agricultural products cold storage, bakery waste heat recovery and automotive dashboard cooling was achieved by using gravity assisted wickless heat pipes (or thermosyphons) and capillary pumped loop. Renewable energy-based electricity generation system developed in this study utilizes thermosyphons to extract stored heat (solar pond, geothermal), to dissipate waste heat to ambient and to store waste heat into phase change materials. Heat pipe provide economical and zero greenhouse gas emission solution for these applications.

1)ENERGY CONSERVATION SYSTEMS

In this section, different energy saving and energy recovery systems that utilizes heat pipes as one of the integral functional elements are discussed.

2)Data Center Cooling Systems

Electric power consumed by datacenter electronics and the cooling cost associated with them are massive. Cooling cost includes the capital and operation costs associated with the active and backup cooling equipment. It has been established from past trends and future forecasts that power consumed by datacenters is one of the major loads on the electric power station and it nearly doubles every five years. Looking at more tangible comparison, power usage byUS datacenters in 2011 is equivalent to power consumed by more than 11 million US houses or yearly electricity needs of whole Los Angeles city. The gravity of the problem is well understood from these massive power and cost figures. Out of the total power consumed by datacenter facility, cooling infrastructure takes up more than 50% electric load which is a huge percentage and therefore represents major cost overhead. Datacenters house mission critical computer systems and associated components for companies and organizations. Due to importance of the stored data and round clock demand on the availability of the datacenters, it is imperative to provide them with the backup power system to support computing equipment as well as their cooling systems. At present, the backup technologies used to power the cooling system are diesel generator, micro gas-turbine or electric battery based. It is evident that most of the present backup systems use non-renewable energy sources like oil or gas to produce power which degrades earth‟s atmosphere by greenhouse gas emission.

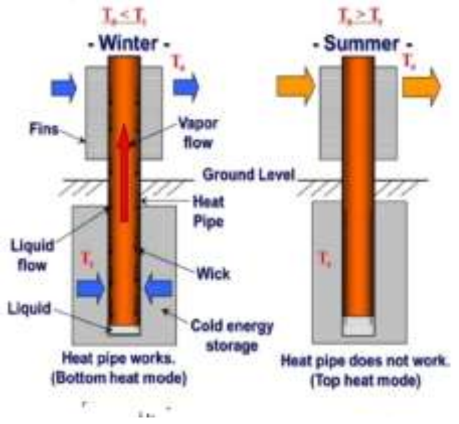


Figure 7 thermal diode character of heat pipe

Batteries need electricity from grid to maintain their charge level and produce environmental contamination during their disposal. Due to the massive size of datacenters, it can be argued that backup cooling systems size and extent of sources (oil, gas or electricity) needed to power them is also substantial. It should be noted that it is not only the running cost of the non-renewable backup systems but also the environmental damage caused by them is considerable. Based on the above discussion, it can be concluded that propositions of energy conservation system for datacenters can save substantial electricity (thus running costs) and greenhouse gas emissions to the environment.

3) Heat Pipe Heat Exchanger Pre-Cooler

In the proposed pre-cooler system the heat pipes transfers the cold energy from the ambient to the coolant flowing inside the pre-cooler duct in real-time thereby cooling it by certain degrees, depending on the pre-cooler design and ambient air temperature, before it enters chiller to achieve the designed cold plate inlet temperature for datacenter servers.

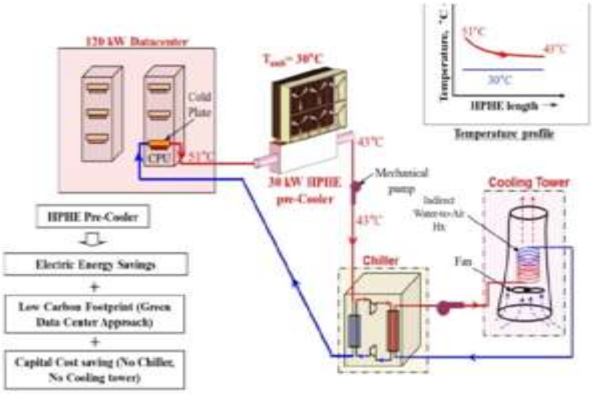


Figure 8 Datacenter facility with HPHE pre cooler

Figure 8 shows the schematic of the data center facility with the pre-cooler integrated between the data center racks and chiller (Wu et al., 2011). The coolant used to extract heat from the data center server is mixture of water and propylene glycol (50-50% by volume). For the 120-kW data center, the pre- cooler has been designed to handle one fourth (30 kW) of the heat load for 30 ºC ambient temperature which represents the upper limit of summer time temperature for Poughkeepsie, New York.

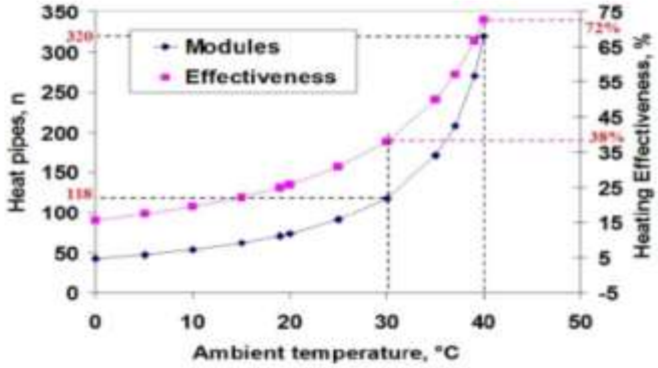


Figure 9.Dependence of hphe pre cooler size and heating effectiveness on Designed ambient temperature

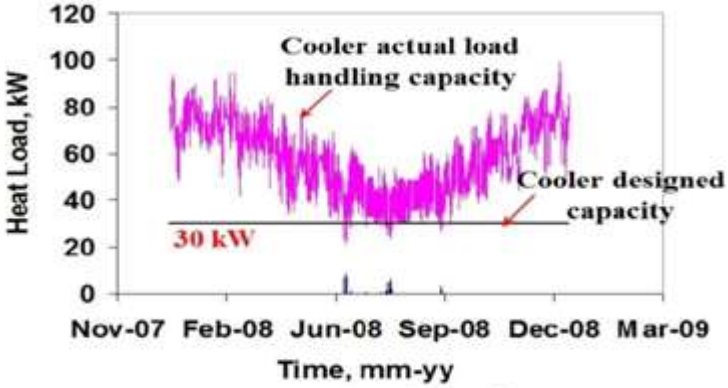


Figure 10 Yearly heat load handling capability of hphe pre-cooler

The size and performance of the HPHE pre-cooler is very dependent on the designed ambient air temperature (in this case 30 ºC). Figure 3 presents the effect of the ambient temperature on the HPHE size and effectiveness. It should be noted that the designed temperature is location dependent therefore to install the similar capacity heat exchanger at hotter location (e.g. Singapore), the size will be much larger. In Figure 4, the yearly load handling capability of the HPHE pre-cooler has been estimated. It is evident that the exchanger is able to dissipate the designed heat load (30 kW) through the year with capacity higher than designed value during most time of the year, except peak summer season. The main cost associated with the HPHE Pre-cooler is heat pipe and tank cost. Based on the yearly performance of the precooler, it is estimated that the payback period for the designed HPHE pre-cooler will be around 2.8 years.

4) Storage Emergency Cooling System

For ice storage system, the cold energy from the below zero winter ambient is captured by heat pipe and used to convert storage water into ice. This ice is stored throughout the year inside the well-insulated underground storage as emergency cooling support for datacenter facility in case of any electricity disruption to the main chiller equipment. In the normal operational mode, data center is cooled by using chiller and cooling tower arrangement as shown in Figure 11. During the unavailability of the chiller due to system failure or power disruption, the three-way control valves can channel the hot coolant coming from the data center to the underground ice storage.

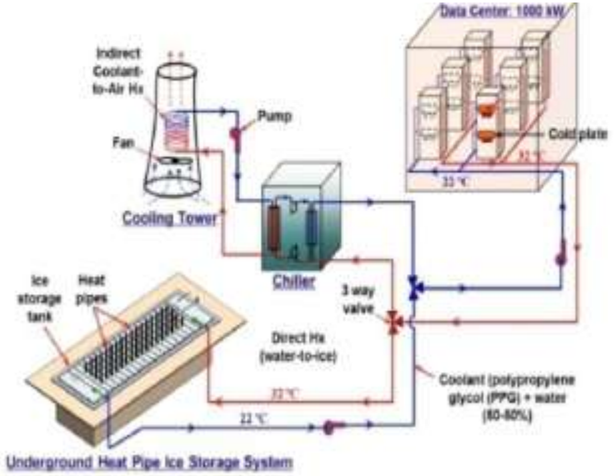


Figure 11 Data center facility with heat pipe ice storage system

The ice storage system comprise of number of ice storage module which is made up of thermosyphon as ice charging component using sub-zero ambient temperature and coil heat exchanger as ice discharging component through which hot water propylene (PP) glycol mixture (used as coolant in data center facility) can be pumped whenever the failure of the primary cooling equipment occurs. As an alternative arrangement, the individual coil heat exchanger for each heat pipe can be replaced with the tube-type single heat exchanger, with inlet and outlet headers, that can extract cold energy from multiple ice generation spots (around heat pipe circumference). During ice storage charging process, the individual thermosyphon will extract heat from the high temperature storage media (water in underground storage tank) to sub-zero winter ambient resulting in phase change of water to ice. Depending on the size of the data center and number of hours of failure support required, number of ice storage module can be combined together to form an overall backup cooling system as shown in Figure 5. In the present case, emergency ice storage system is designed to support data center with 1 MW output heat load capacity for 6 hours (Wu et al., 2010; Wu et al., 2010; Singh Detailed theoretical analysis was conducted to estimate the yearly ice generation capacity of individual thermosyphon module for the given heat pipe dimensions and climatic conditions of the chosen location. In the current analysis, heat pipe consists of stainless-steel tube with 50.8 mm outer diameter, 3 m evaporator length and 3 m condenser length. The condenser portion consists of 300 aluminum fins with 300 mm x 300 mm area and 1 mm thickness. R134a was used as working fluid due to its superior thermal performance at lower temperatures as compare to other heat pipe working fluids. The climatic conditions for Poughkeepsie in New York were used to estimate thermosyphon ice generation capability.

5) Renewable Energy Systems

In this section, different solar and geothermal based renewable energy systems that utilizes heat pipes as an integral element are discussed

6)Heat Pipe Turbine

A new concept for power generation from solar, geothermal or other available low-grade heat sources using a Heat Pipe Turbine or a Thermosyphon Rankine Engine (TSR) was developed and tested (Nguyen et al., 1999). The basis of the engine is the modified thermosyphon cycle, with its excellent heat and mass transfer characteristics, which incorporates a turbine in the adiabatic region. Figure 14 shows the details of the heat pipe turbine with that consists of closed vertical cylinder with an evaporator, an insulated (adiabatic) section and a condenser. The turbine is placed in the upper end between the evaporator and condenser sections, and a plate is installed to separate the high-pressure region from the low-pressure region in the condenser. Conversion of the enthalpy difference to kinetic energy is achieved through the nozzle. The mechanical energy developed by the turbine can be converted to electrical energy by direct coupling to an electrical generator.

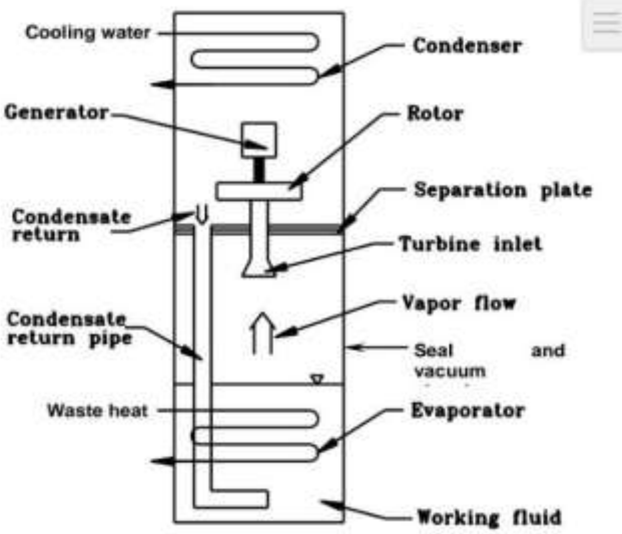


Figure 12 turbine heat pipe

Development of the heat pipe turbine was conducted by fabricating and testing a series of prototypes in the RMIT Laboratories. The aim of the work was to optimize the performance of each successive prototype in order to simplify manufacture and to increase the power output. The first prototype turbine rotated at 600 to 800 rpm but only very low power output was measured. The second prototype was equipped with an impulse turbine and the heat input was specified as 2 kW. The rotational speed of the turbine was up to 3400 rpm, but the power output was still low. In the third prototype the reaction turbine was introduced. The turbine was produced as a hollow disc, including two convergent-divergent nozzles at its periphery. The diameter of the heat pipe was 16 cm and its height 3.15 m. An electrical power output of 5.5 W at 4788 rpm was obtained from a heat input of 4.4 kW. The fourth prototype consistedof a cylinder of height 2.8 m and a diameter of 0.5 m. The turbine configuration was the same as in the third prototype. The heat input was 10 kW and electrical power output of 100 W was obtained at 6000 rpm. Although the efficiency of the proposed heat pipe turbine is low, it has the capability of utilizing very low- grade heat and converts it into useful electricity

7)Geothermal Heat Extraction

A large scale loop type heat pipe for extraction of geothermal energy was developed at Fujikura (Mashiko et al., 1994). The heat pipe of 150 mm outer diameter and 150 m length was manufactured and installed in a geothermal well, with 100 to 150 °C temperature, located at Kyushu Island in Japan, as shown by schematic in Figure 15. Conventional heat pipes would not work properly in the present application by simply enlarging the heat pipe diameter and length because the heat load will cause entrainment and flooding phenomena within the heat pipe. With a long heat pipe heat- transfer performance would deteriorate due to the difficulty of maintaining uniform liquid film throughout the length of the heat pipe. To address these heat transfer issues in a longer vertical evaporator section, an innovative design using liquid feeding tubes with showering nozzles was used in the evaporator.

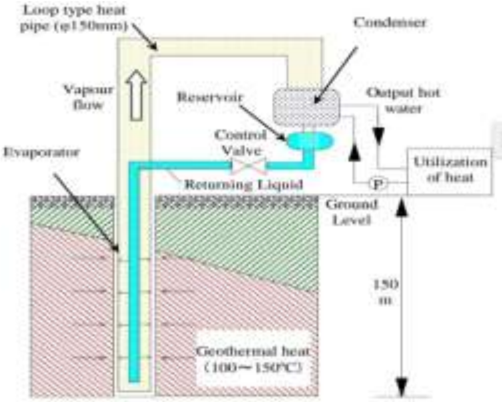


Figure 13 Large Scale Heat Pipe For Extracting The Geothermal Heat

Cross section of evaporator section showing the liquid holding wick and liquid return lines with spurting nozzle are shown in shown in Figure 16. The liquid is fed through a feed tube having a number of nozzles to spray the liquid onto the inner surface of the evaporator of the heat pipe. The spraying of liquid on the evaporator enhances the evaporation heat transfer of the heat pipe. This new concept helps to provide twofold advantage firstly by separating the liquid and vapour phases to avoid entrainment losses and secondly by providing uniform liquid film in the evaporator section for high heat transfer rate.

In the trial tests, the heat pipe was able to continuously extract 90 kW heat at the working temperature of 80 °C. Heat flux at the evaporator was of the order of 3000 W/m2 (Mochizuki et al., 1995). Figure 15 shows the schematic of the demonstration rig. Due to the larger length of the evaporator, the novel concept of the showering nozzle was used to spread thin layer of the liquid over the inside of the evaporator tube. Liquid was returned using gravity effect by multiple return tubes. The nozzles spray the working fluid under hydrostatic pressure due to height of liquid column on the wick structure which provided high evaporative heat transfer with lower thermal resistance.

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