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Influence of Different Parameters on Heat Pipe Performance

Sharmishtha Singh Hada under the guidance of Prof. P. K. Jain
In the Department of Mechanical engineering,

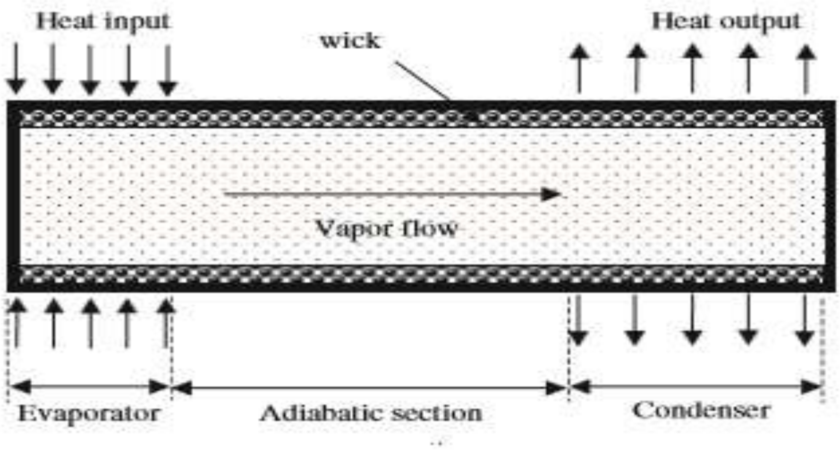
ABSTRACT:
In electrical and electronic industry due to miniaturization of electronic components heat density increases which, in turns increases the heat flux inside it. Scientist and many researchers are doing lot of work in this field for thermal management of devices. Heat pipe is a device that is used in electronic circuit (micro and power electronics), spacecraft & electrical components for cooling purpose. It is based on the principle of evaporation and condensation of working fluid. Heat pipe made up of three main parts are evaporator, adiabatic and condenser sections. In this working fluid vaporise at evaporator and transfers heat to condenser by adiabatic section where heat release to surrounding. Vapour flows possible from evaporator to condenser section due to vapour pressure difference exist between them. Use of heat pipe material, type of working fluid & its property, wick structure, orientation, filled ratio, operating condition, dimensions of pipe has a prominent effect on heat pipe performance. Variation of these parameters for minimum thermal resistance gives better performance.

HISTORY OF HEAT PIPE:
Heat pipe is a device used for maintaining temperature of micro, power electronics devices and aerospace industry. Initially origin of heat pipe occurred since 1836s by A. M. Perkins and J. Perkins, but he toyed with concept of working fluid in only single phase at high temperature. In 1944 R.S. Gougler used another important thing is called wick. This wick is necessary for heat pipe other than thermosyphon. In 1962 G.M. Grover and his co-workers from Los Alamos scientific laboratory made a prototype on the design and coined the name “HEAT PIPE”. In Heat pipe thermal conductivity and phase change phenomenon is used to dissipate the heat to surrounding.

I. INTRODUCTION

In electronics devices because of the miniaturization, heat flux density increases. Increase in density responsible for excessive temperature rise of material that will increase thermal stresses in it. Heat pipe is a device based on the principal of thermo hydrodynamics of working fluid. It is comprises of three section evaporator, adiabatic and condenser section. Working fluid carries the heat from heat source by evaporation and rejected it at condenser by condensation. Vapour pressure difference b/w evaporator and condenser drive the vapour from evaporator to condenser. Latent heat librates at condenser to due to phase change phenomenon. It gives the advantage of heat transfer between small temperatures difference over a considerable distance. Heat pipe made up of three important things pipe material, working fluid and wick structure. Material used for heat pipe should have high thermal conductivity and compatibility with working fluid used. Material used for heat pipe may be copper, nickel, stainless steel & molybdenum and working fluid are water, cesium, sodium and bismuth generally copper is used because of high thermal conductivity. Use of working fluid depends upon the thermo-physical properties of working fluid like saturation temperature, latent heat, specific heat, viscosity, density. Wick structure use for capillary action for returning the working fluid from condenser to evaporator. Four types of wick structure may be used are grooved, wire-mesh, sintered metal power and wire screen wick. To find out the value of performance parameter different methodologies such as numerical analysis and experimental analysis is necessary.

II. HEAT PIPE CONSTRUCTION AND OPERATIONAL DETAILS



Heat pipe is consisting of three sections are:
(a) Evaporator section
(b) Adiabatic section
(c) Condenser section

In the evaporator section i.e. at heat source working fluid vaporises and converts into vapour. Then this vapour is passed through an adiabatic section (where no heat loss occurs) to condenser section (heat sink) where latent heat of fluid releases to surroundings. Temperature of working fluid always exists between triple point and critical point. Working fluid always remains in saturated state inside the heat pipe. In radial direction working fluid composed of three sections are:
(a) Container/ shell
(b) Working fluid
(c) Wick structure (liquid flow section)

(i) CONTAINER: container is a shell or tube to contain the working fluid and wick within itself. It is made up of different types of material are copper, aluminium, steel, tungsten, titanium. Material used for container must have higher thermal conductivity and must be compatible with working fluid used. Generally copper is used for higher thermal conductivity approximately 400 w/m° C and low cost as compared to other material.
(ii) WORKING FLUID: working fluid selection in heat pipe depends on the type of material used. Different types of working fluids are water, ammonia, ethanol, methanol, acetone, lithium, sodium, bismuth, nitrogen, helium. Nitrogen or helium used for low temperature application and lithium, sodium and potassium used for high temperature applications.
(iii) WICK STRUCTURE: It may be axial grooved, wire mesh, sintered powder, and woven fibreglass. Wire mesh made up of particular type of material like steel and alloy. For gravity assisted heat pipe grooved wick heat pipe gives higher heat transfer rate and for capillary against gravity sintered metal powder is efficient for heat transformation. Wick is used to return the working fluid after condensation to evaporator section by capillary action of working fluid due to surface tension.

TYPES OF HEAT PIPE:
(1) Vapour chamber (Flat heat pipe)
(2) Variable conductance heat pipe (VCHP)
(3) Pressure controlled heat pipe
(4) Diode heat pipe
(5) Thermosyphon
(6) Rotating heat pipe

(1) Vapour chamber/ Flat heat pipe: - This type of heat pipe closed loop at both the end and hermetically sealed hollow vessel. This is used mainly where high power and high heat fluxes applied to a relatively small evaporator.
(2) Variable conductance heat pipe: - This type of heat pipe is used to maintain the temperature of electronics being cooled while the power and sink condition is changing with time. This have two additional arrangement as compared to standard heat pipe are (1) Reservoir (ii) non condensable gases in addition to working fluid. NCG in standard VCHP is argon and helium in thermosyphon heat pipe.
(3) Pressure controlled heat pipe: - The PCHP heat pipe have tight temperature controlled ability. Here evaporator temperature is responsible for either vary the volume of reservoir or change the mass of non-condensable gases.
(4) Diode heat pipe: - This heat pipe which have high thermal conductivity in forward direction

and low thermal conductivity in reverse direction.

(5) Thermosyphon: - This is the gravity assisted heat pipe because condenser is located above the evaporator so after the condensation liquid returns to evaporator by gravity action.

(6) Rotating heat pipe: - In this type of heat pipe centrifugal action is used for returning of working fluid to evaporator.

III. LITERATURE SURVEY

As given in history heat pipe is initially developed as a tube in 1836s. After that 1944s Gougler give the concept of a tube with wick structure for return the working fluid to make it in running condition even evaporator situated above the condenser, but he was unable to give the results by experimental testing when using the wick for capillary action. During 20 years progress in the field of heat pipe is non-productive. The revolutionary work over heat pipe with wick structure comes into existence since 1960s by Grover. He designed the pipe prototype and coined the name to this HEAT PIPE. Since 1969s NASA did lots of work over this technology in spacecraft for thermal control and in satellite equipments. So with the increasing demands of electronics equipments in industry, commercial and domestic purpose the use of heat pipe becomes important and effective way to maintain the temperature. Faghri et al. [1] studied the effect of conduction in axial direction in the fluid and the pipe wall of the heat pipe for forced convective laminar flow at the impermeable wall with blowing and suction across it. Faghri et al. [2] observed the overall performance of the concentric annular heat pipe with an emphasis on enhance in the heat carrying capacity as compared to the conventional heat pipe and also theoretically predicted the capillary limitation in a concentric annular heat pipe. Chang [3] developed the mathematical model to derive the effective thermal conductive property and porosity of the copper screened wick. The mathematical results were compared with the previous experimental results and mathematical expressions. Peterson et al. [4] mathematically predicted the maximum heat transport in micro heat pipes. Wang et al. [5] had done experimental investigation to analyze the thermal performance of a flat plate heat pipe. Zhu et al. [6] predicted the performance of a disk-shaped heat pipe and presented the optimum design obtained from the study of parameters and the analysis of the boiling limitation. Wang et al. [7] analytically predicts the performance in unsteady state of a flat plate heat pipe for start-up and shutdown operations. Mahmood et al. [8] had done the experimental investigation on the performance limiting factors of micro heat pipe of non-circular cross-section. They have analysed three different cross-sections. Thomas et al. [9] analyze the steady-state performance of a helically grooved copper heat pipe with ethanol as a working fluid under various heat inputs power and transverse body force field. Hopkins et al. [10] had done experimental study to analyze performance characteristics of three copper-water flat miniature heat pipes for horizontal and vertical orientation individually under steady state condition. Han et al. [11] studied the thermal characteristics of grooved heat pipe with hybrid nano -fluids and analysed for the variables related to properties such as volume concentration, heat pipe inclination, and cooling water temperature. Mwaba et al. [12] studied numerically the influence of wicking structure on heat pipe performance. Wang et al. [13] experimentally and analytically investigated the beat possible heat carrying capacity with the effects of mesh number, wire diameter, number of layers and tilt angle. Mahmood et al. [14] carried out an experimental investigation on the performance limitation of micro heat pipe with other than circular cross-section. They have analysed three different cross-sections (circular, semicircular, and rectangular) but hydraulic diameter (D = 3 mm) is same with 3 different inclination angles (0°, 45°, 90°) using water as the working fluid. Das et al. [15] go detailed into investigating the increase of thermal conductivity with temperature for nanofluid particle with base fluid as water and particles of 23 AlO or CuO as suspension material, and the results indicated an increase of characteristics that increase with temperature, which makes the nanofluid even more attractive for high energy density applications in comparison with usual room temperature measurements reported earlier. Rosenfeld [16] also mentioned the necessasity of heat transfer within the wall and the porous wick in the case of an asymmetric heat input. Due to complexity in obtaining a solution analytically for overall heat pipe operation no. of numerical models have been presented. Vafai et al. [17] have developed comprehensive pseudo-three-dimensional analytical models for asymmetrical ¯at-shaped, including both disk-shaped and at-plate, heat pipes. They incorporated liquid flow, secondary vapour flow and the effects of liquid vapour hydrodynamic coupling and non-Darcian transport in their models.

IV. FACTORS AFFECTING THE HEAT PIPE PERFORMANCE:

(1) Material used for container
(2) Properties of working fluid used
(3) Type of wick structure
(4) Dimensional variation
(5) Source and Sink temperature
(6) Power input at evaporator section
(7) Orientation of heat pipe
(8) nano- particles

Material used for container or vessel: - Material used should have high thermal conductivity and low thermal resistance. Material must be compatible with the working fluid used and should not react with it. Selection of material depends on type of working fluid used and selection of working fluid depends on the operating temperature of heat pipe. Mostly copper is used as a container material with water as a working fluid with high thermal conductivity of 400 w/m° k, so the material is selected on the basis of operating temperature of heat pipe. Generally steel, copper, aluminium, composite materials are used for low and room temperature application but for high temperature heat pipe refractory materials are used, and lining are used to prevent corrosion.

Properties of working fluid: - Working fluid generally used in heat pipe operation are water, helium, nitrogen, liquid silver, ammonia, methanol, ethanol, for low and medium operating temperature range but for high operating temperature range generally the sodium, lithium, cesium, potassium, indium used. Impurities in working fluid reduce the overall performance of heat pipe. To measure the effectiveness of working fluid one parameter is used and mathematical expression to find it is given below:

Liquid transport factor (N) = $\frac{\rho\sigma\lambda}{\mu}$

Where ρ is density of fluid, σ is the surface tension in fluid, and μ is dynamic viscosity of fluid.

Woking fluids and temperature ranges:

Working Fluids	Melting Point, K at 1 atm	Boiling Point, K at 1 atm	Useful Range, K
Helium	1.0	4.21	2–4
Hydrogen	13.8	20.38	14–31
Neon	24.4	27.09	27–37
Nitrogen	63.1	77.35	70–103
Argon	83.9	87.29	84–116
Oxygen	54.7	90.18	73–119
Methane	90.6	111.4	91–150
Krypton	115.8	119.7	116–160
Ethane	89.9	184.6	150–240
Freon 22	113.1	232.2	193–297
Ammonia	195.5	239.9	213–373
Freon 21	138.1	282.0	233–360
Freon 11	162.1	296.8	233–393
Pentane	143.1	309.2	253–393
Freon 113	236.5	320.8	263–373
Acetone	180.0	329.4	273–393
Methanol	175.1	337.8	283–403
Flutec PP2	223.1	349.1	283–433
Ethanol	158.7	351.5	273–403
Heptane	182.5	371.5	273–423
Water	273.1	373.1	303–473
Toluene	178.1	383.7	323–473
Flutec PP9	203.1	433.1	273–498
Naphthalene	353.4	490	408–478
Dowtherm	285.1	527	423–668
Mercury	234.2	630.1	523–923
Sulphur	385.9	717.8	530–947
Cesium	301.6	943.0	723–1173
Rubidium	312.7	959.2	800–1275
Potassium	336.4	1032	773–1273
Sodium	371	1151	873–1473
Lithium	453.7	1615	1273–2073
Calcium	1112	1762	1400–2100
Lead	600.6	2013	1670–2200
Indium	429.7	2353	2000–3000
silver	1234	2485	2073–2573

Type of wick structure: - Wick structures used in heat pipe are axial groove, screen mesh, and sintered powder wick. Actually wick is used for returns of working fluid to evaporator without gravity assisted heat pipe or heat pipe in different orientation except thermosyphon. Capillary pressure difference is responsible for exerting a driving force for returning of working fluid to evaporator section. In case of thermosyphon heat pipe axial grooved wick is used and offer low thermal resistance but when liquid flow against gravity then sintered metal power is used for effectively transmission of liquid without any difficulty.

Dimensions of heat pipe:- Thermal conductivity varies with heat pipe length. For very large length of heat pipe thermal conductivity becomes up to 100000w/ m °k in comparison to high thermal conductive material like copper of 400 w/m °k. Thermal conductivity of heat pipe directly related to heat pipe length. Thickness of heat pipe offers a thermal resistance, so it should be sufficient enough to effectively transformation of heat. For example if total length of heat pipe is 1000 mm then for this thickness of heat pipe and wick should not be more than 2 mm.

Source and sink temperature:- Standard heat pipe is a constant conductance device in which operating temperature is set by source and sinks temperature. In this temperature drop occurs linearly. Standard heat pipe applications in satellite and research balloon industry or electronics being overcooled when the sink temperature reduces at low power. When sink temperature or power changed then it is called variable conductance heat pipe. That is used for maintaining the temperature of electronics being cooled.

Power input at the evaporator section:- High power input at the evaporator causes sonic, entrainment and boiling limit. In this vapour will move with sonic velocity from evaporator section because of constant transport power and too much temperature gradient. During start up at low temperature with high power input also create a problem. So power and evaporator temperature are related to each other.

Orientation of heat pipe:- If the heat pipe operates in a vertical plane then condenser should be above the evaporator for gravity assists for retuning of working fluid to evaporator, otherwise against gravity flow heat pipe, capillary force must be sufficient enough to work against gravity. Except thermosyphon, wick is necessary for all types of heat pipe. The type of wick should be such that have a large capillary pumping pressure against vapour pressure difference exist between evaporator and condenser.

Use of Nanoparticles with working fluid:- OHP performance can be improved by addition of alumina in working fluid; it will decreases the thermal resistance up to 0.14°C/w. in 1996 Argonne laboratory raise the thermal conductivity of heat pipe by the use of nano- sized metallic and non metallic tiny particles. Nanofluids used with water are TiO2, Al2O3, Al etc.

V. Conclusion

Heat pipe affected by many parameters. While designing a heat pipe many parameters considered for effective transmission of heat to heat sink. Firstly material for container, wick must have high thermal conductivity and compatibility with working fluid used. Working fluid in heat pipe operation remains in equilibrium with its vapour pressure and have a saturated state in overall operation. Heat transfer coefficient depends on the type of wick used. Wire screen wick offers heat transfer coefficient up to 5 w/ m^2°C and sintered powder wick offer a heat transfer coefficient up to 20 w/ m^2°C. Material used for wick may be same as that of container material. Capillary limit causes the high heat flux at evaporator section, that completely dry out cause's velocity of vapour reach to sonic velocity, that is not desirable. This will reduce the effect of dissipation of heat from pipe. High temperature heat pipe require a large length heat pipe and minimum thickness for high capacity and low thermal resistance respectively. Source and sink temperature decide the operating temperature of heat pipe. If the sink temperature changed then the thermal conductivity of material will also change because of the flexibility in operation of heat pipe. High Power input and low temperature at the source causes start up problem in operation while constant transport power and low temperature causes vapour velocity reach to sonic velocity. Orientation of heat pipe also affect the performance of pipe, so in horizontal plane highly efficient wick should be used and for pipe in vertical plane thermosyphon type heat pipe mostly used because gravitational force is responsible for returning action without the use of wick structure. The use of nano- particles in base fluid will improves the heat transport capability of working fluid as compared to conventional heat pipe and this will reduce the thermal resistance and changed the filled ratio too. Filled ratio is the volume of working fluid in respect of volume of heat pipe. High filled ratio will hinder the pulsation bubble and low filled ratio offer easy pulsation of bubble but dry out the section completely.

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