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REVIEW ON GEOMETRICAL STUDY OF HEAT PIPE

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ABSTRACT

This paper presents about the heat pipe and its technology. A comparative study of different properties of heat pipes has been studied based on their geometry, flow and fluid properties. The study was done on straight, loop, curved and helical heat pipe.

I. INTRODUCTION

Heat pipe is a device which is used for high heat transfer at low temperature difference. There are many practical errors in the flow of fluid in heat pipe when compared to the theoretical study. This occurs due to pipe bends, fittings and in geometrical design [1]. After many observations we can say that helical pipe has higher rate of heat transfer than straight pipe. Depending upon operating temperature suitable fluid is used in the heat pipe. Based on temperature range fluid is selected on particular properties based on the temperature range like Wettability of wick and wall materials, Good thermal stability, vapor pressures not too high or low over the operating temperature range, high thermal conductivity, high latent heat, low liquid and vapor viscosities and high surface tension. These properties depend upon the operation limits (viscous limit, entertainment limit, sonic limit, boiling limit, capillarity limit) [2].

Compact heat pipe is used for electronic devices. Loop Heat pipe (LHP) is widely used for cooling compact electronics. A LHP consists of an evaporator, with fine pored wick structure and a condenser section connected with separate vapor and liquid flow lines. To transfer heat it uses latent heat of evaporation and condensation, and depends on capillary pressure generated by the wick structure for the circulation of the working fluid around the loop. In addition, many efforts were made on designing miniature loop heat pipe. As MLHP is a compact enclosure it consists of flat evaporators because it is considered as suitable design. Condensers of different shape like fin and tube type, concentric tube type and collector type are used in the mLHP depending on heat removal conditions. Four different types of start-up behavior can be seen depending on the pre-start-up liquid distribution inside the evaporator and compensation chamber. LHP has start-up issues due to intensive heat flow from the evaporation zone to the compensation chamber at very low heat loads. The performance issues are mainly due to occurrence of the large vapor super heating and thermal oscillations phenomena, mainly at low heat load. These oscillations are due to thermal and hydrodynamic interaction between the compensation chamber, condenser and evaporator section. [3].

Selection of operational fluid; Type of fluid used in the heat pipe primarily depends upon operating temperatures. Once the temperature is decided fluid is selected on particular properties. [4]. the temperature range is decided based on the melting point and boiling point of the fluid. The operational temperature range should be above the melting point and the boiling point should lie in between the temperature range. Refer table

1. Selection of metal casing is mainly based on the operational fluid, temperature range, and external conditions. Refer table 2.

Table 1

Working fluid	Compatible material	Incompatible material
Water	Stainless steel, copper ,silica , titanium	Aluminum ,Inconel
Ammonia	Aluminum, stainless steel, cold rolled steel, iron, nickel	Copper
Methanol	Stainless steel, copper, silica, nickel, brass	Aluminum
Acetone	Aluminum, copper, stainless steel, brass, silica	
Freon-11	Aluminum	
Freon-21	Aluminum, iron	
Freon-113	Aluminum	
Heptane	Aluminum	
Dowtherm	Stainless steel, copper, silica	
Lithium	Tungsten, tantalum, molybdenum, niobium	Stainless steel, nickel, Inconel, titanium
Sodium	Stainless steel, nickel, Inconel, niobium	Titanium
Ceslum	Titanium, niobium	
Mercury	Stainless steel	Molybdenum, nickel, tantalum, Inconel, titanium, niobium
Lead	Tungsten, tantalum	Stainless steel, nickel, Inconel, titanium, niobium
Silver	Tungsten, tantalum	Rhenium

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Table 2

	MELTING POINT (^{0}C)	BOILING POINT AT ATM.PRESSURE (^{0}C)	USEFUL RANGE (^{0}C)
helium	-271	-261	-271 to -269
nitrogen	-210	-196	-203 to -160
ammonia	-78	-33	-60 to 100
acetone	-95	57	0 to 120
methanol	-98	64	10 to 130
Flutec PP2	-50	76	10 to 160
ethanol	-112	78	0 to 130
water	0	100	30 to 200
toluene	-95	110	50 to 200
mercury	-39	361	250 to 650
sodium	98	892	600 to 1200
lithium	179	1340	1000 to 1800
silver	960	2212	1800 to 2300

Conductivity of a wick in a heat pipe depends on the conductivity of the base material out of which the wick material is made, the porosity of the wick material and geometrical characteristics such as tortuosity. The selection of the wick structure depends on a lot of factors. [5], working fluid properties, heat pipe container material and heat pipe working conditions (e.g. gravity-assisted or gravity opposed). Basically a wick has two purposes in a heat pipe. The main purpose is to generate capillary pressure to transport the working fluid from the condenser to the evaporator. Secondly the wick must be able to distribute the liquid around the evaporator section.

The number of possible wick types (e.g. composite wicks) have a high manufacturing cost and complexity is virtually endless. More advanced wick designs. In this study, the focus is on homogeneous wick designs capable of performing against gravity. A sintered powder, a wrapped screen mesh and randomly stacked small diameter fibers are studied as wick structures.

The resistance offered to the heat flow in a heat pipe can be sub categorized into various types: contact resistance (R_c), thermal resistance due to thermal conduction (R_{RD}), thermal resistance due to the wick (R_W), thermal resistance due to temperature drop at the liquid vapour interface (R_T), resistance offered due to metal casing (R_S), resistance offered due to vapour column (R_V). Refer fig.1.3.

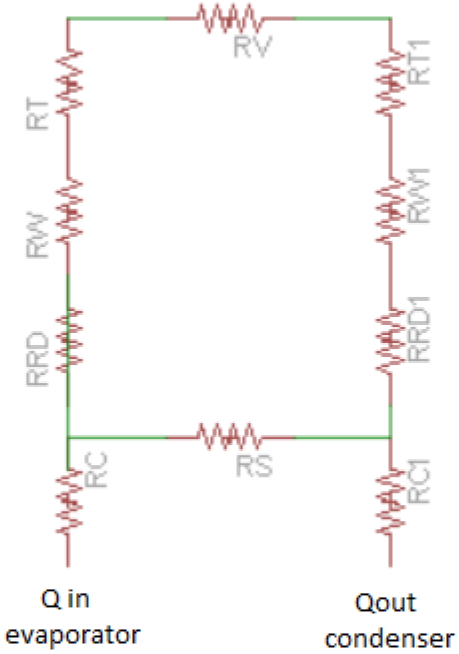

Fig.1

Equivalent thermal resistance network in a heat pipe. [5]. on basis of heat transfer application, the helical coil tubes are better than straight tubes. The centrifugal force due to the curvature of the tube results in the development of secondary flows (flows perpendicular to the axial direction) which assist in mixing the fluid and enhance the heat transfer.

On the comparison of helical heat pipe and straight heat pipe over the superiority; the first attempt has been made by Dean to describe mathematically the flow in a coiled tube. A first approximation of the steady motion of incompressible fluid flowing through a coiled pipe with a circular cross-section is considered in his analysis. The result shows that the onset of turbulence did not depend on the value of the Re or the De. It was concluded that the flow in curved pipes is more stable than flow in straight pipes. It was also studied the resistance to flow as a function of De and Re. The difficulty is in estimating the area of the coil surface available to heat transfer. It is expected that there would be possible dead-zones in the area between the coils where the fluid would not be flowing. The heat would then have to conduct through the fluid in these zones, reducing the heat transfer effectiveness on the outside of the coil. [6, 7]

To improve heat transfer performance of heat exchangers, the enhancement techniques can be divided into two groups: active and passive techniques. The active techniques require external forces like fluid vibration, electric field, and surface vibration. The passive techniques require special surface geometries or fluid additives like various tube inserts. Due to their compact structure and high heat transfer coefficient, helically coiled tubes have been introduced as one of the passive heat transfer enhancement techniques and are widely used in various industrial applications. [8]

In recent years, many investigations have been conducted concerning on the oscillation in a pulsating heat pipe with open end. Effort has been devoted primarily to the modeling of the system that causes self-sustained thermally driven oscillations. It has been shown that single vapor slug occupies the closed end side on which the heating section (maintained at a constant temperature) is located, and the evaporation and condensation over a liquid film left on the tube wall during the growth of the vapour slug toward the open end plays an important role in the oscillation of the liquid plug. However, the occurrence and stagnation of the dry-out region in the heating section may cause a fatal increase in the tube wall temperature under the imposed heat flux conditions. The structure of the heating section to ensure the stable oscillation with large amplitude leading to high heat transport performance without any dry-out, and the heat transport mechanism of the resulting oscillation with such large amplitudes as significant portion of the liquid plug will be pushed out from the open end to be exchanged with the liquid of the cooling section have not been clarified yet. Based on the above considerations, the authors finally realized a self-excited oscillation-type heat pipe consisting of a single straight tube [11].

II.METHODOLGY OF DIFFERENT AUTHORS

2.1 Geometrical Analysis of Heat Pipe

2.1.1 Flow

There are three types of flow observed in any pipe i.e., laminar, turbulent, laminar and turbulent flow. These flows are mainly described using Reynolds number, using this number many properties of fluid can be determined. The flow properties vary at different points on the pipe. In heat pipe the flow can be subdivided into primary and secondary flow.

2.1.2 Role of Dimensionless Quantities

There are six dimensionless quantities which determine the flow of fluid and they are curvature and torsion (based on pipe geometry), Prandtl number and bulk Reynolds number (fluid properties), gravitational Richardson number and centrifugal Richardson number. This Richardson number occurs when there is change in density gradient. To the pipe geometry and fluid properties fixed values are assigned only Richardson number has been varied to study the effect of gravitational and centrifugal buoyancy.

2.2 Fluid Property Limits

This deals with how fluid effects with different properties. At low temperature viscous nature of fluid is higher than at high temperature which effects the startup in heat pipe. So, maximum viscosity should not exceed 0.1 at low temperature. Due to high temperature vapor goes to sonic state which leads to high velocity and effects the pressure. So, heat flux is maintained. To maintain entertainment limit the values are taken on based weber number. Capillarity limit refers to gravity, capillarity, liquid and vapor. These values are calculated based on certain assumptions like the liquid properties do not vary along the pipe and the wick is uniform along the pipe the pressure drop due to vapor flow can be neglected. Some other factors like wick material, material of heat pipe made up off.

2.3 Working of mLHP

Compensation chamber of mLHP receives liquid from condenser via liquid line and this compensation chamber is directly linked to the evaporator. The saturation temperature of the compensation chamber is influenced by its heat exchange with evaporator, ambient and incoming liquid from the condenser at any given load. The condenser was fin. To transfer heat from condenser to atmosphere by forced convection of air with temperature of 22 ± 2°C a centrifugal fan can be used. It has a vapor line and liquid return line. A heat load simulator in the form copper block with two cartridge heater can be used to test thermal performance of mLHP. It was operated in the horizontal orientation with evaporator and condenser at the same level in gravity field. The permissible temperature of the heat source should be taken for cooling applications. For successful start-up, the fluid circulation around loop and development of the constant temperature at evaporator and across the vapor line is necessary. The thermal resistance is offered by the mLHP from evaporator to condenser and it is used to access the heat transfer performance of device. It is given by

$$R_{mLHP} = \frac{\left(T_{evap} - T_{cond} \right)}{Q} \quad \mathbf{1}$$

T_{evap} – external temperature of evaporator, T_{cond} – condenser temperature i.e. average of condenser inlet temperature, condenser fin temperature and condenser outlet temperature, Q – Heat load applied.

2.4 Comparison of Fluids

This deals with how fluid effects with different properties. At low temperature viscous nature of fluid is higher than at high temperature which effects the startup in heat pipe. So, maximum viscosity should not exceed 0.1 at low temperature. Due to high temperature vapor goes to sonic state which leads to high velocity and effects the pressure. So, heat flux is maintained. To maintain entertainment limit the values are taken on based weber number. Capillarity limit refers to gravity, capillarity, liquid and vapor. These values are calculated based on certain assumptions like the liquid properties do not vary along the pipe and the wick is uniform along the pipe the pressure drop due to vapor flow can be neglected. Some other factors like wick material, material of heat pipe made up off. Three fluids water, acetone and methanol tested in copper tube with specified temperature range. Based on above properties tests are performed to obtain best working fluid. Where water showed good results at those conditions i.e., in laptops.

2.5 Wick Types

In this the thermal characteristics are observed for various wick types. In gravity assisted heat pipes below 20W there is no significant difference in the drop in temperature but with increasing heat transfer rate there is a significant difference in the temperature drop. Sintered is worse whereas screen mesh and fiber types show similar characteristics. This occurs because of dry point where the capillary action the wick reaches a limit and the liquid gets super-heated instead of being a saturated vapor. Different graphs are drawn comparing various characteristics of the wick in both gravity opposing and gravity assisted model. The wick characteristics were studied in various conditions and the optimal wick structure can be selected based on the heat input and other conditions.

2.6 Comparison of Helical and Straight Pipe

The main difference between helical and straight pipes is the flow of the fluid. In the straight pipes the flow is along the pipe direction. In helical pipes there are two flows in the pipe; one flow is along the pipe length and the second flow is along the radius which is due to the centrifugal force acting on the fluid and this causes the uniform temperature in the helical cross section due to the thorough mixing of the fluid. Cold tap water was used for the fluid flowing in the annulus. The water in the annulus was circulated and the flow was controlled by a valve. Hot water for the inner tube was heated in a tank with the thermostatic heater. This water was circulated via pump. The flow rate for the inner tube was controlled by flow metering valve.

Fig.2

Heat transfer coefficient and heat transfer rates were determined based on the measured temperature data. The heat is flowing from inner tube side hot water to outer tube side cold water.

Mass flow rate of hot water (Kg/sec), $m_H = Q_{HOT}\left(LPH\right) \times \rho$ (Kg/m3)

2

Mass flow rate of hot water (Kg/sec), $m_C = Q_{COLD}\left(LPH\right) \times \rho$ (Kg/m3)

3

Velocity of hot fluid (m/sec),

$$V_H = \frac{\square_{HOT}}{1000 \times Area}$$

4

Heat transfer rate of hot water (J/sec), $q_H = m_H \times C_P \times \square t_{hot} \times 1000$

5

Heat transfer rate of cold water (J/sec), $q_C = m_C \times C_P \times t_{cold} \times 1000$

6

Average heat transfer rate,

$$q_{avg} = \left(q_H + q_C\right) / 2$$

7

The heat transfer coefficient was calculated with, $U_0 = \frac{Q}{A \times LMTD}$

8

The overall heat transfer surface area was determined based on the tube diameter. LMTD is the log mean temperature difference, based on the inlet temperature difference ΔT1, and outlet temperature difference ΔT2

$$LMTD = \frac{(\Delta T1 - \Delta T2)}{(ln\ (\Delta T1 \times \Delta T2))}$$

9

The overall heat transfer coefficient can be related to the inner and outer heat transfer coefficients by the following equation

$$\frac{1}{U_0} = \frac{A_0}{A_i H_i} + \left(\frac{A_0 \times ln\ (\frac{D_0}{D_i})}{2\pi KL} \right) + \frac{1}{H_0}$$

10

di ,do are inner and outer diameters of the tube respectively. K is thermal conductivity of wall material and L, length of tube (stretch length) of heat exchanger. After calculating overall heat transfer coefficient, only unknown variables are hi and ho convective heat transfer coefficient inner and outer side respectively, by keeping mass flow rate in annulus side is constant and tube side mass flow rate varying, $h_i = CV_i^n$, V_i are the tube side fluid velocity m/sec., the values for the constant, C, and the exponent, n, were determined through curve fitting. The efficiency of the heat exchanger was calculated by

$$\eta = \frac{1 - e^{-\alpha}}{(1 - C\min / C\max \times e^{-\alpha})}$$

11

, η = 93.33%.

The Reynolds number,

$$Re = \frac{(\rho \times V \times D)}{\mu}$$

12

Dean number,

$$De = \frac{\rho \upsilon D}{(\frac{D}{2R})^{1/2}}$$

13

Friction factor,

$$F = (\Delta P \times D) / (2 \times \rho \times V^2 \times L).$$

14

-Effectiveness of heat pipes

When mass flow rate through the shell increases the overall heat transfer coefficient increases, and it is observed that hot mass flow rate inside tube increases the overall heat transfer coefficient also increases. Overall heat transfer coefficient of counter flow heat exchanger is high compared to corresponding parallel flow exchanger. Helical coil counter flow has maximum overall heat transfer coefficient and straight tube parallel flow has lowest overall heat transfer coefficient for corresponding readings. Comparative study is carried out between helical coil heat exchanger and straight tube heat exchanger. The effectiveness of heat exchanger greatly affected by hot water mass flow rate and cold water flow rate. When cold water mass flow rate is constant and hot water mass flow rate increased the effectiveness decreases. Increase in cold water mass flow rate for constant hot water mass flow rate resulted in increase in effectiveness. For both helical coil and straight tube heat exchangers with parallel and counter flow configuration this result obtained. Helical coil counter flow is most effective in all these conditions and straight tube parallel flow heat exchanger is least effective. Overall heat transfer coefficient on other hand increases with increase in hot water mass flow rate and cold water mass flow rate.

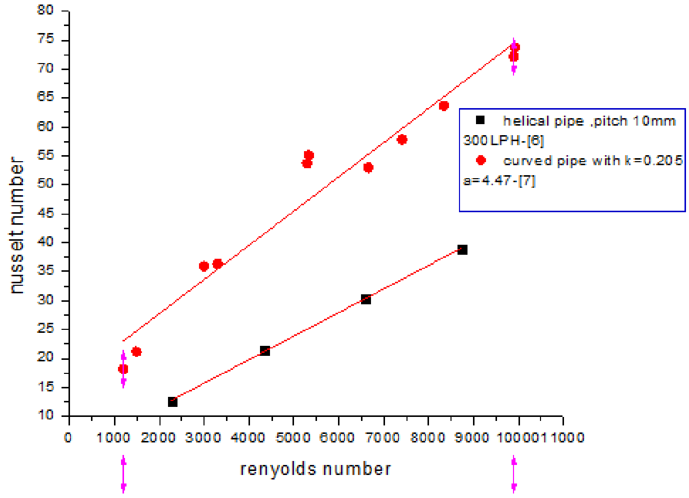

Fig.1: Comparison of Reynolds number vs nusselt number of helical and curved pipe

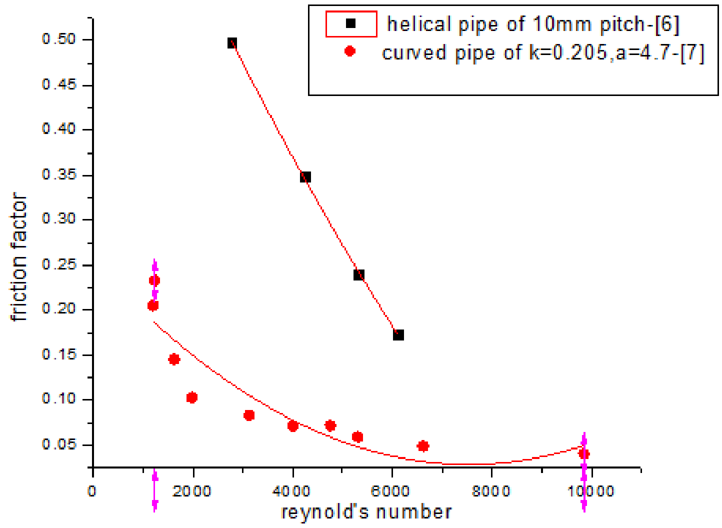

Fig.2: Comparison of Reynolds number vs friction factor of helical and curved pipe

Fig.1 shows that curved pipe has more heat transfer compared to the curved pipe but at the same time Fig.2 shows that helical pipe high friction factor than curved pipe. This shows there are more loses in helical pipe compared to curved pipe and helical pipe require more power input to produce same amount of heat at comparative geometry

2.7 Heat Transfer Enhancement with the Presence of Nano Fluids

The presence of Nano particles in the fluid can increase the heat transfer rate due to properties of the Nano particles. It is observed that there is an increase in thermal conduction and increase in heat transfer co efficient by a large margin. In the case of slip condition the change in properties with presence of Nano particles is large compared to the non-slip condition. There is a variation in the properties with the change concentration of in Nano particles.

2.8 Heat Properties

When periodic oscillation of a vapor plug with a large amplitude is excited in a horizontal orientation and continues for a long period of over 8000 s without ceasing ,the heat transport rate and the effective thermal conductivity increase with heating power up to approximately 75W and 40 kW/(m K) respectively. The heat transport can be characterized by three factors: (a) latent heat transport due to the condensation of vapor onto the liquid film, (b) enhanced heat diffusion induced by oscillating motion of the liquid plug in the heat transport tube, and (c) liquid exchange due to oscillating motion between the heat transport tube and the cold liquid reservoir. Based on the measurement of the effective thermal conductivities for several types of heat transport tube, some relevant factors will be excluded, it has been inferred that, rather than Factor (a), Factor (c) enhances the heat transport significantly in the SST-PHP.

III. CONCLUSION

Based on the above study, for a compact device we use mLHP. The geometry of this heat pipe can be designed using six dimensionless quantities and type of fluid can be chosen based on fluid property related to the application and three fluids has been tested based on that and with different wick materials. It showed that helical pipe has high efficiency compared to curved pipe.

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