

Review on Effect of Gravity Supported Heat Pipe

Keval Nikam¹, K.V.L.Bhuvaneshwary², Khushali Bhisikar³, Trupti Bhoskar⁴

Asst. Professor, Department of Mechanical, Dr.D.Y.Patil Institute of Engineering, Management and Research, Akurdi,
Pune, India^{1,2,3}

Asst. Professor, Department of Mechanical, SKNSITS, Lonavala, India⁴

ABSTRACT : Heat pipe is device working with phase changes of working fluid inside hermetically closed pipe at specific pressure. The phase changes of working fluid from fluid to vapour and vice versa help heat pipe to transport high heat flux. The article deal about construction and processes casing in heat pipe during operation. The effect of gravity may also be used to bring the condensate back to the hot end. For this purpose, the heat pipe may be kept vertical with hot section at the bottom. Since the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end. Thus the structure will have a high effective thermal conductance is studied.

KEYWORDS: Phase Change Material, Evaporation, heat pipe, thermal conductance.

I.INTRODUCTION

The heat pipe is an efficient heat conductor which is used to transfer heat from one location to another with small temperature gradient. It is divided into three sections, evaporator,adiabatic, and condenser. Heat is added through the evaporator section, where the working fluidis vaporized. The vapour then passes through the adiabatic section. The vapour releases its latentheat and gets liquefied in the condenser. The circulation is completed by the return condensed Liquid to the evaporator through the wick or packed bed under the driving action of capillaryforces. Depletion of liquid by evaporation causes the liquid vapour interface in the evaporator to enter in the wick surface and the capillary pressure is developed there. This capillary pressure pumps the condensed liquid back to the evaporator for re-evaporation, i.e. the heat pipe can continuously transport the latent heat of vaporization from evaporator section to the condenser section without drying out the wick. The process will continue as long as the flow passage for the working fluid is not blocked and a sufficient capillary pressure is maintained.

The effect of gravity may also be used to bring the condensate back to the hot end. For this purpose, the heat pipe may be kept vertical with hot section at the bottom. Since the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end. Thus the structure will have a high effective thermal conductance.

II.LITERATURE SURVEY

Over the past 40 years, extensive studies have been conducted in order to provide a deep understanding of the heat pipe operation and hence to improve its performance. Faghri et al. [3] investigated experimentally and theoretically the condensate heat transfer coefficient and the flooding limit of conventional and annular two-phase closed thermosyphon using R-113 and acetone as working fluids. It was found that, a significant increase in the heat transfer coefficient was obtained for annular thermosyphons than conventional ones. Faghri and Thomas [4] studied experimentally and theoretically the capillary limit of the concentric annular heat pipe (two concentric pipes of unequal diameters). The

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

capillary wicks can be placed on both the inside of the outer pipe and the outside of the inner pipe. The results show a significant increase in the heat capacity per unit length compared to conventional heat pipe with the same outer diameter. Sakr and Abd El-Aziz [5], and Abd El-Aziz et al. [6] and carried out an experimental investigation to study the heat transfer performance for gravity assisted heat pipes with different working fluids. They found that, the heat pipe performance is affected by the working fluids and is improved with increasing the operating pressure. Abo El-Nasr and El-Haggar[7] performed an experimental investigation to study the effect of the wick structures on the heat transfer characteristics of the heat pipes. They found that, increasing the number of screen wick layers (up to 16 layers) enhance the ability of the heat pipe to transfer heat. Zuo and Faghri[8] presented a thermodynamic analysis of the heat pipe. It was concluded that, in order to transport

heat through a longer distance, a working fluid with a larger latent heat of vaporization, a smaller vapor viscosity and a larger vapor density is preferred. Taher et al. [9] carried out an experimental investigation to study the heat transfer parameters (h & C) of gravity assisted heat pipes with inserted concentric finned tubes. It was found that, the tested heat transfer parameters of a smooth heat pipe were significantly improved by inserting a concentric finned tube. Osman conducted experimentally the effect of inserting screen layers from brass material, on the heat transfer performance of gravity assisted heat pipe, using R-11 as the working fluid. The results indicated that, the heat transfer parameters of the heat pipe were improved by increasing the wire mesh number and the number of mesh layers. Berbish studied experimentally the effect of surface roughness on the heat transfer performance of gravity assisted heat pipes with wire mesh screen wicks, using R-12 as the working fluid. It was concluded that, the tested heat transfer parameters of the heat pipe were increased with the increase of the surface roughness, screen thermal conductivity, and screen wick layers number. El-Kady et al. carried out an experimental investigation to study the performance of three geometries of heat pipe, using pure water as the working fluid. The effects of applied heat flux and the geometry of the outer surface of the condenser section was examined. The results show that the overall heat transfer coefficient, and boiling and condensation heat transfer coefficients have higher values for knurled sample and longitudinal grooved sample compared with smooth sample. Heat and mass transfers in porous media are of growing interest in a wide range of engineering domains. A wide variety of applications involving convective transport in porous media include utilization of geothermal energy, and design of packed bed reactors. Udell conducted a one-dimensional, steady state analysis of the heat and mass transfer in porous media saturated with the liquid and vapor phases of a single component fluid. The effects of capillarity, gravity forces, and phase change were included. It was found that the heat transfer was increased several orders of magnitude beyond pure conduction due to an evaporation, convection and condensation phenomenon similar to conventional heat pipe operation. De Vries established a phenomenological theory of combined heat and moisture transfer in porous media. The study revealed that, water movement through porous media is often caused by a temperature gradient. Water evaporates from hot regions and moves across the gas-filled pores by diffusion and condenses on the cold region thus releasing its latent heat of vaporization. Crowe et al. Performed an experimental and theoretical investigation to study the performance limits of a copper heat pipe with copper porous wick using water and R-11 as working fluids. The results showed that, shorter adiabatic section length gives better performance. It was also found that, the maximum heat flow rate was obtained for heat pipes having low porosity wick. Bouddour et al. developed a theoretical model to study the heat and mass transfer in wet-porous wick in presence of evaporation-condensation. It was found that the heat transfer occurs by conduction and convection in presence of phase change by evaporation-condensation. From the previous survey, the heat transfer performance of heat pipes having wicks filled with porous medium has not been studied extensively. Accordingly, the purpose of the present work is to explore some aspects of the heat transfer characteristics for heat pipe with wicks filled with porous medium.

III. THEORY

The three basic components of heat pipe are:

1. Container
2. Working fluid
3. Wick or capillary structure.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

1. Container

The function of the container is to isolate the working fluids from the outside environment. Hence, it has to be leak proof and maintain the differential pressure across its walls, so that heat can transfer from and into the working fluid. Simultaneously, it should have high strength to weight ratio and high thermal conductivity.

2. Working Fluid

The variety of fluid characteristics must be examined in order to determine most acceptable of these fluids. Prime requirements are compatibility, good thermal stability and wettability with wick and wall material.

3. Wick or Capillary Structure

It is porous structure made of materials like steel, aluminum, nickel or copper in various ranges of pore sizes. The prime purpose of wick is to generate capillary pressure to transport the working fluid from the condenser to the evaporator. It must be able to distribute the liquid around the evaporator section to any area where heat is likely to be received by the heat pipe.

WORKING OF HEAT PIPE

Wick structure is secured to the inside wall of the container saturated with working fluid. The container is then evacuated and hermetically sealed. Because of the strong vacuum inside the tube, the boiling temperature of the working fluid is reduced to the point where it is in equilibrium with its own vapour. When heat is added to one end of the tube (Evaporator), the liquid vaporizes and expands to fill the tube. The rapid generation of vapour creates a pressure gradient that forces excess vapour to move to colder end (Condenser). The lower temperature causes vapour to condense. The condensate is returned to the evaporator end by the capillary pumping action on the wick. The cycle is then repeated.

The performance of heat pipe is affected by gravity. Optimum performance is achieved when the pipe is vertical with the condenser section directly above the evaporator. In this position, gravity aids the pumping action in the wick. However, heat pipes can operate in any position and are bi-directional.

IV. EXPERIMENTAL SETUP

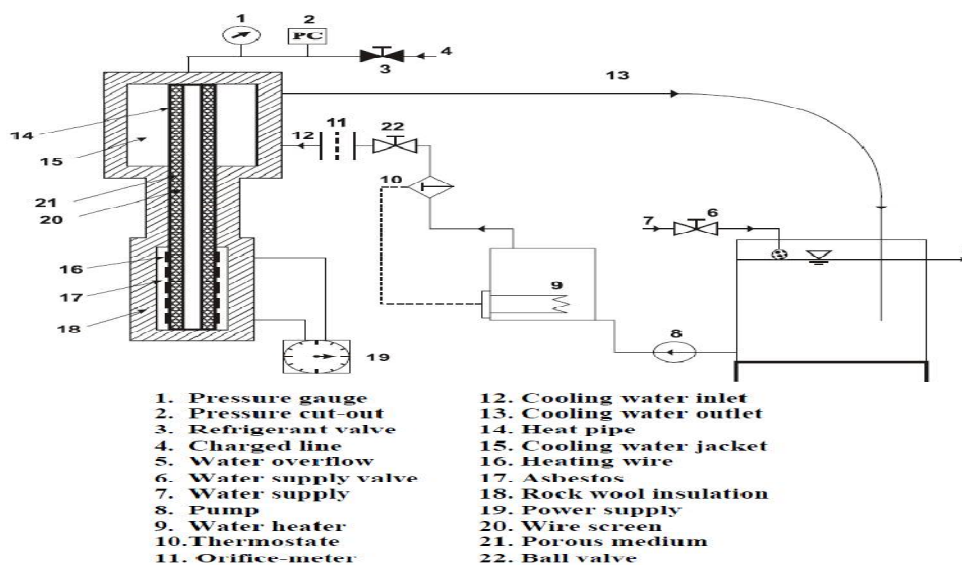


Fig. (1) Experimental test rig layout

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

The experimental apparatus which is used to investigate the heat transfer characteristics of gravity assisted heat pipe with wick filled with porous medium is shown schematically in Fig. (1). It consists mainly of the vertical heat pipe, insulation layers, the heating wire, the cooling water circuit and different measuring instruments. A heat source is applied to the lower section of the heat pipe (evaporator section) to evaporate the liquid. The vapor flows upward to the upper section of the pipe (condenser section) where the latent heat of condensation is removed by circulating cooling water. The condensed liquid returns back to the evaporator by gravity. A mild-steel wire screen mesh of thickness 0.8 mm is fixed rigidly and concentrically inside the heat pipe in a hollow cylindrical form of about 8.0 mm outer diameter. The heat pipe wick (space between the screen outer diameter and the heat pipe inner diameter) is filled with porous medium, as shown in Fig.(2). The tested heat pipe is made of hard copper material, of 28.5 mm inside diameter, 1.5 mm thickness, and a total length of 400 mm. The length of the evaporator section is 140 mm, adiabatic section is 120 mm, and condenser section is 140 mm. The cooling water flow rate is measured using a calibrated orificemeter. A manual ball valve is installed before the orifice-meter to control the water flow rate. The electrical heater is covered with an electric insulation. A cylindrical rock wool insulation of thickness of 25.4 mm sheltered with aluminum foil is used for covering the whole heat pipe to minimize the heat loss. The outer and inner insulation surface temperatures are measured at different axial positions along the pipe to calculate the radial heat loss. Heat input is determined from the measured electrical power input as corrected for heat loss through outer wall, based on the average inner and outer insulation temperatures. The heat loss is found to be less than 2 %.

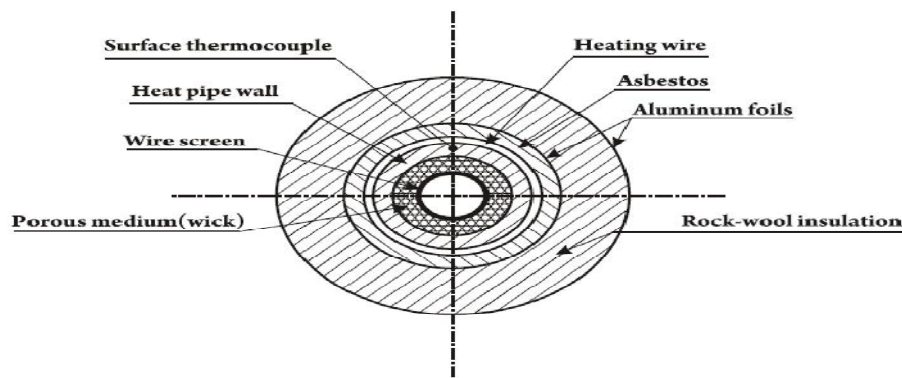


Fig. (2) Cross sectional view in the evaporator zone of the heat pipe

Figure (2) show the details of cross-sectional view in the evaporator zone of the heat pipe. Surface temperatures are measured at eleven axial stations along the heat pipe as shown in Fig. (3). Calibrated thermocouples are fixed at each test position with the hot junction of each embedded in 0.5 mm deep drilled holes to be in good contact with the pipe surface. The calibrated thermocouples are made from copper constantan wires of 0.25 mm diameter with ± 0.1 oC accuracy. The fluid temperatures are measured using six thermocouples inserted inside the heat pipe, where two thermocouples are press fitted into the evaporator, adiabatic, and condenser sections as shown in Fig. (3).

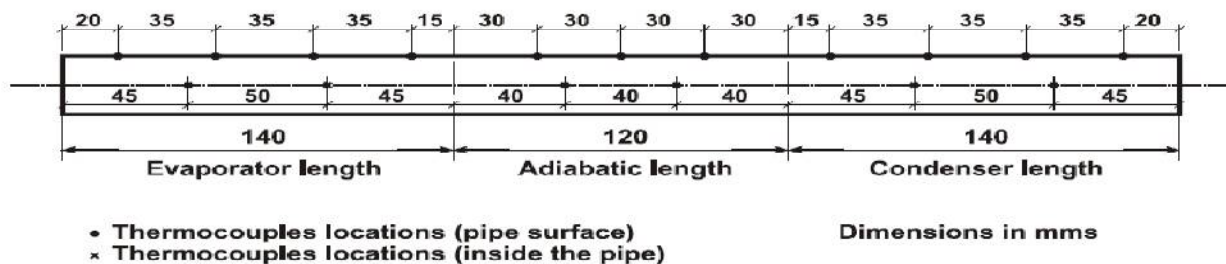


Fig. (3) Details of the thermocouples locations

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

The fluid temperature in the adiabatic section is used to measure the average saturation temperature corresponding to the operating pressure. This location is selected to avoid the temperature of the superheated boiling liquid in the evaporator or the sub-cooled condensate in the condenser [3&4]. The heat pipe is designed to have the facility of changing the porous medium with different particles diameters and materials. At first the heat pipe without packing material (smooth) is used for calibrating the experimental apparatus and also for comparison with cases using packing material. The tested parameters are shown in Table (1).

Operating pressure, (bar)	2.0, 2.85, 3.95 and 5.10
Porous medium particles diameters to inner heat pipe diameter ratios, (d/D)	0.1684, 0.1404, 0.1123 and 0.0912
Porous medium particles material	Gravel, glass, ceramic, marble, granite, mild-steel, and nickel
ks/kf for gravel, glass, ceramic, marble, granite, mild-steel and nickel respectively.	5.2, 12.5, 14.9, 32.3, 36.1, 533.6 and 1156.7

Seven different packing materials are tested. The ratios of packing materials conductivity to liquid refrigerant R-11 conductivity at pressure equals to 2.0 bar (ks/kf) are given in Table (1).

TEST PROCEDURE

The power is supplied via a variac transformer to adjust the heat flux. At each power setting, after reaching the steady state condition, data are recorded concerning the water flow rate, inlet and outlet water temperatures, current, voltage, heat pipe wall temperatures, the outer wall insulation temperatures, and the working pressure. The main heat transfer parameters for the tested heat pipe are the evaporator heat transfer coefficient and the overall thermal conductance.

The evaporator heat transfer coefficient, h , is calculated as:

$$h = q / (T_e - T_a) \tag{1}$$

where:

q : the heat rate flux based on the evaporator outer surface area, (W/m²).

T_e : average surface temperature along evaporator section, (K).

T_a : fluid saturation temperature (along adiabatic section), (K).

The overall thermal conductance of the heat pipe is calculated as:

$$C = Q / (T_e - T_c) \tag{2}$$

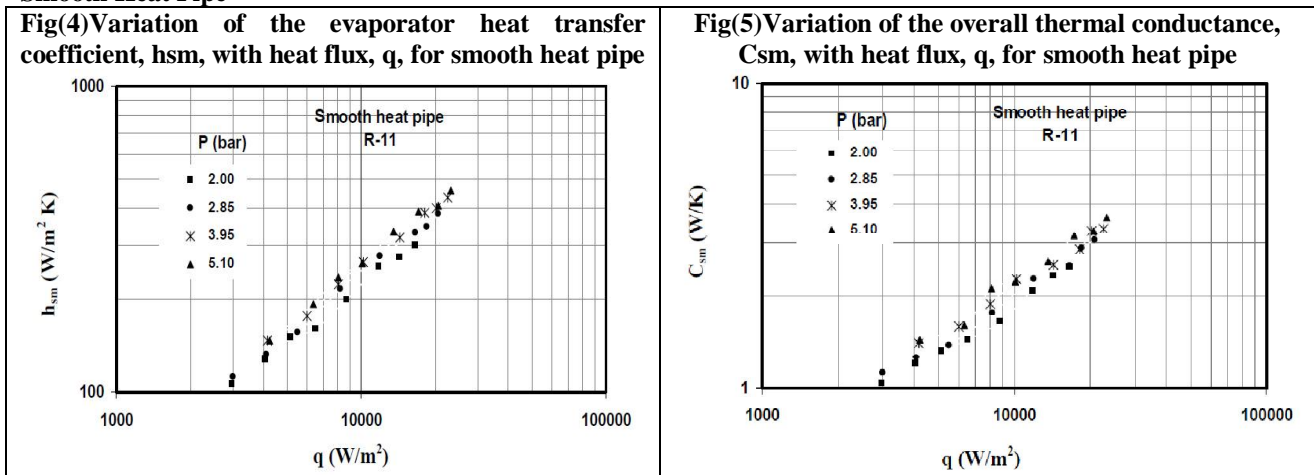
where:

Q : electric heat rate input, (W).

T_c : average surface temperature along condenser section, (K).

V.PERFORMANCE OF HEAT PIPE

Smooth Heat Pipe



Figures (4) and (5) show the variations of the evaporator heat transfer coefficient, hsm, and the overall thermal conductance, Csm, (tested heat transfer parameters) for a smooth heat pipe without porous medium wick, against the heat flux at different operating pressures, respectively. It is found that the increase in both heat flux and operating pressure enhance significantly the tested heat transfer parameters. For a constant operating pressure, increasing the heat flux, the liquid in contact with the pipe surface will become progressively heated and bubbles will form nucleation sites. These bubbles will transport some energy to the heat pipe surface by latent heat of vaporization and will also increase the heat transfer parameters. At constant heat flux, an increase in heat transfer parameters is found with the increase of working pressure according to the dependence of the temperature drop of the working fluid on the pressure drop along the heat pipe. Consequently the pressure drop and the temperature drop along the heat pipe decrease by increasing the working pressure as a result of decrease in vapor specific volume for a constant vapor mass flow rate by transferring a given heat input.

The evaporator heat transfer coefficient, hsm, and the overall thermal conductance, Csm, are correlated as functions of operating pressure and heat flux using the measured data plotted in

Figs. (4) and (5) for smooth heat pipe, as:

$$h_{sm} = 0.43 P^{0.18} q^{2/3} \tag{3}$$

and

$$C_{sm} = 0.014 P^{0.25} q^{0.51} \tag{4}$$

The present correlations for the evaporator heat transfer coefficient, Eq.(3), and the overall thermal conductance, Eq. (4) are valid with the present experimental results within $\pm 5.8\%$ and $\pm 6.7\%$ deviations.

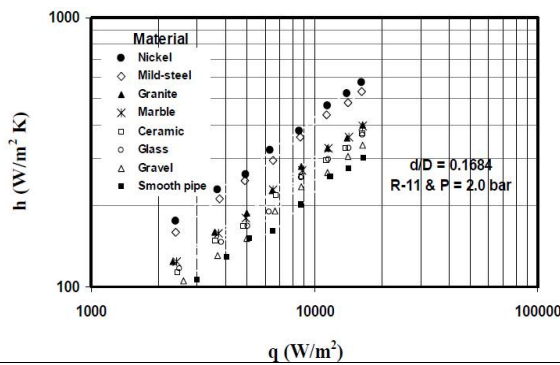
Porous Wicked Heat Pipe

The particles of the porous media used in the experiments were made of gravel, glass, ceramic, marble, granite, mild steel and nickel covering a wide range of solid thermal conductivities and particle diameters.

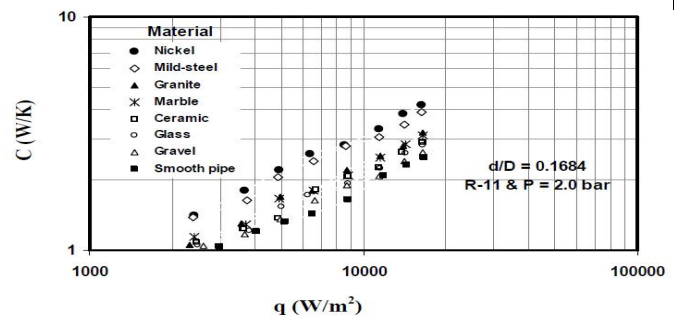
Effect of porous medium thermal conductivity

For heat pipes having wicks filled with solid particles, of special interest for studies of heat transfer augmentation is the question of how much the heat transfer parameters are improved relative to an equivalent smooth pipe (without porous medium) at similar conditions. The variations of the evaporator heat transfer coefficient and the overall thermal conductance (tested heat transfer parameters) versus the heat flux for different packing material thermal conductivities at constant particle to the heat pipe diameter ratio of about $d/D=0.1684$, are shown in Figs.(6)and(7),respectively.

Fig(6)Variation of the evaporator heat transfer coefficient, h , with heat flux, q , for porous wicked heat pipe at different packing materials and $d/D=0.1684$



Fig(7)Variation of the overall thermal conductance, C , with heat flux, q , for porous wicked heat pipe at different packing materials and $d/D=0.1684$



Effect of porous medium particle diameter

The variations of the tested heat transfer parameters with the heat flux for different particle to heat pipe inner diameter ratios (d/D).

The particles of the porous medium were made of nickel material with $0.0912 \leq d/D \leq 0.1684$. For the same packing material, it is observed that the tested heat transfer parameters are increased with the decrease of the particle to the heat pipe diameter ratio. This may be attributed to increase the contact conduction area of solid particles touching the heat pipe surface with the smaller particle diameter .

It is found that, the average maximum value of (h/h_{sm}) is about 2.40, and of (C/C_{sm}) is about 2.10. These values are obtained for smaller particle to heat pipe diameter ratio ($d/D = 0.0912$). Also, for the same operating pressure, it is observed from these figures that the enhancement ratios (h/h_{sm}) and (C/C_{sm}) are nearly constant over the present heat flux range. Finally, correlations for the enhancement ratios of both the evaporator heat transfer coefficient (h/h_{sm}) and the overall thermal conductance (C/C_{sm}) are obtained as functions of the particle to heat pipe diameter ratio, (d/D) and the particle to liquid thermal conductivity ratio, (k_s/k_f) using the present experimental data, as:

$$h/h_{sm} = [0.644 + 0.048 (D/d)](k_s/k_f)^{0.102} \quad (5)$$

and

$$C/C_{sm} = [0.768 + 0.017 (D/d)^{1.32}](k_s/k_f)^{0.085} \quad (6)$$

These correlations, Eqs. (5) and (6), for both (h/h_{sm}) & (C/C_{sm}) are in good agreement with the present experimental data within $\pm 9.1\%$ & $\pm 9.5\%$ maximum deviations.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

VI. CONCLUSION

The evaporator heat transfer coefficient and the overall thermal conductance (tested heat transfer parameters) of the heat pipe increase with increasing both the operating pressure, and the heat flux. The tested heat transfer parameters for smooth heat pipe are correlated as a function of the heat flux, q , and the operating pressure, P , as:

$$h_{sm} = 0.43 P^{0.18} q^{2/3}$$

and

$$C_{sm} = 0.014 P^{0.25} q^{0.51}$$

The obtained correlations for h_{sm} & C_{sm} fit the present experimental data within $\pm 5.8\%$ and $\pm 6.7\%$ maximum deviations, respectively. The tested heat transfer parameters for porous wicked heat pipe increase significantly with the increase in the packing material conductivity, and with the decrease in the particle to the heat pipe diameter ratio. For porous wicked heat pipe using nickel packing material, it is found that the average maximum value of (h/h_{sm}) is about 2.40, and of (C/C_{sm}) is about 2.10. These values are obtained for smaller particle to heat pipe diameter ratio ($d/D=0.0912$). Correlations for the augmentation of the tested heat transfer parameters are obtained as functions of the particle to heat pipe diameter ratio, (d/D) and the particle to liquid thermal conductivity ratio, (k_s/k_f) , as:

$$h/h_{sm} = [0.644 + 0.048(D/d)](k_s/k_f)^{0.102}$$

and

$$C/C_{sm} = [0.768 + 0.017(D/d)^{1.32}](k_s/k_f)^{0.085}$$

These correlations for (h/h_{sm}) , and (C/C_{sm}) are in good agreement with the present measured data within $\pm 9.1\%$ and $\pm 9.5\%$ maximum deviations, respectively.

REFERENCES

1. Peterson, G. P., 1994, An introduction to heat pipes - modeling, testing, and applications, Published by John Wiley & Sons Inc., New York, USA.
2. Faghri, A., 1995, Heat pipe science and technology, Taylor & Francis, Washington D. C., USA.
3. Faghri, A., Chen, M. -M., and Morgan, M., August 1989, "Heat transfer characteristics in two-phase closed conventional and concentric annular thermosyphons," ASME Journal of Heat Transfer, Vol. 111, pp. 611-618.
4. Faghri, A., and Thomas, S., November 1989, "Performance characteristics of a concentric annular heat pipe: Part I - Experimental prediction and analysis of the capillary limit," ASME J. of Heat Transfer, Vol. 111, pp. 844-850.
5. Sakr, M. H., and Abd El-Aziz, R. M., 1995, "An investigation into the effect of the working fluid properties on the performance of a gravity assisted heat pipe." Al-Azhar Engineering Fourth International Conference, Al-Azhar University, Egypt, pp. 147-159.
6. Abd El-Aziz, R. M., Sakr, M. H., Ayad, S.S. and Afefy, A. A., 1997, "An investigation of the wick configuration on the performance of the gravity assisted heat pipe," The Tenth International Conference of Mechanical Power Engineering, Assiut University, Assiut, Egypt, pp. 501-528.
7. Abo El-Nasr, M., and El-Haggag, S. M., 1996, "Effective thermal conductivity of heat pipes," Scientific Bulletin, Ain Shams University, Faculty of Engineering, Vol. 31, No. 1, pp. 316-327.
8. Zuo, Z. J. and Faghri, A., 1998, "A network thermodynamic analysis of the heat pipe," International Journal of Heat and Mass Transfer, Vol. 41, No. 11, pp. 1473-1484.
9. Taher, S. H., Berbish, N. S., and Osman, A. M., 2003, "Heat transfer characteristics of gravity assisted heat pipes with inserting concentric finned tubes," Engineering Research Journal, Helwan University, Faculty of Engineering, Mataria, Cairo, Egypt, Vol. 89, pp. M14-M41.