International Engineering Research Journal

Performance Analysis of Multilayer Mesh Wick Heat Pipe Using Cuprous Oxide

Saurabh B. Raut †, Dr. J.S. Gawande ‡

†Student, Department of Mechanical Engineering. JSPM's RSSOER. Savitribai Phule University, Pune, Maharashtra, India
‡Professor & Head of Mechanical Engineering Department, JSPM's RSSOER Savitribai Phule University, Pune, Maharashtra, India

Abstract

*An experimental study of heat transfer performance of heat pipe for examining the effect of multilayer screen mesh wicks and cuprous oxide (nano-fluid) as working fluid has been conducted. Three heat pipes were fabricated. In this heat pipes with different layers of screen mesh wicks are used to improve capillary action of working fluid. Heat pipes having 375 mm length and 39 mm diameter are selected. The different mesh configurations are namely 100+150 mesh, 100+2*150 mesh and 4*150 mesh with wire diameter of 0.9 mm. The concentration of cuprous oxide nano-fluids for the experimentation purpose is 1.0wt%. The heat pipes are tested with water and cuprous oxide as working fluid for different heat inputs i.e. 35w, 50w 100w, 120w and 150w. The thermal resistance and heat transfer coefficient are determined with the help of observations obtained. In this way, effect of different heat inputs on wick type heat pipes with different layers of screen mesh using water and CuO as working fluids has been studied.*

Keywords:*Heat pipe, Cuprous Oxide, Thermal resistance, Multilayer mesh wick.*

1. Introduction

There is revived interest within the use of heat pipes for management of thermal energy attributable to increase heat flux necessities and thermal energy restraint in some industrial applications. The performance of heat pipe having wick is characterised by each its most heat transport rate and its implicit thermal resistance. In the wicked heat pipe there are various failure that restrain the heat transfer rate. In several moderate-temperature applications, the heat transport rate is usually restricted by the capillary pressure which will be generated by the wick structure. Hence, there had been considerable analysis targeted on developing higher models to forecast the pressure drop that happens in heat pipes with wick. This has enclosed varied inspection analytically and numerically which has resolved the many equations for liquid flowing from the wick and also the vapour flow for a spread of various conditions, together with many heat sources and transient start-up of the heat pipe. There has been less analysis specializing in predicting the heat transfer achieved for given temperature distinction by these heat pipes before the bounds are encountered. The heat pipes thermal performance is usually foreseen employing a one-dimensional thermal resistance network, wherever all element of the heat pipe is modelled by associate thermal resistance.

In applications typically lower-temperature, it's usually thought that thermal resistance of wick structure which is saturated within the condenser and evaporator side recital for liberal of the heat pipe thermal resistance. Thus, correct models for the heat transfer through these sections of wick are necessary for predicting the implicit thermal resistance of a wicked heat pipe. In most cases, it's assumed that the heat transfer at the condenser and evaporator side happens by physical phenomenon through the saturated wick with condensation or evaporation at the surface. This shows/represents the higher limit of the thermal resistance of the wick. Variety of models and correlations for the effective physical phenomenon of wire screen mesh wicks are developed. These models vary from the empirical, semi-empirical, and also the analytical. The predictions from these models take issue by associate order of magnitude for an equivalent wick structure. The saturated wick's thermal resistance depends on the pure mathematics and properties of the wick and also the physical phenomenon of the operating fluid however are comparatively freelance of heat flux. many experiments have shown that the screen mesh wicked heat pipes general thermal resistance is non-linear, notably at low heat fluxes the heat pipe may be a extremely effective passive device for sending heat at high rates over considerable distances with extraordinarily tiny temperature drops, exceptional flexibility, straightforward construction and straightforward management with no external pumping power.

Several millions heat pipes are currently factory-made every month since all trendy laptops use heat pipes for hardware cooling. Future physics system particularly computers and facility are expected to be of tiny size, light-weight however with compact parts that unleash terribly high magnitudes of heat. These miniaturized systems generate giant heat fluxes throughout operation, that warrant the event of economical thermal management systems. totally different modules like heat pipes, heat sinks, heat spreaders and vapor chambers are accustomed take away inevitable heat spots within the electronic systems.

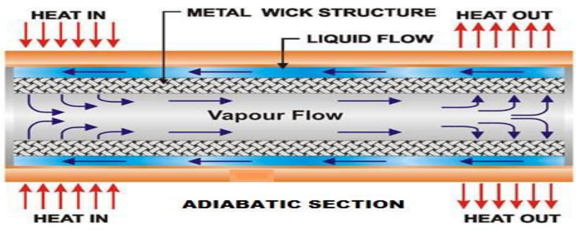

Fig.1 Principle of Heat Pipe

Thermal management is that the generic want of any chilling system. Heat pipes and vapor chambers have emerged because the most acceptable technology and price effective thermal resolution attributable to their glorious heat transfer capabilities, high potency and structural simplicity. essentially heat pipes are 2 section heat transfer devices. Involve associate exhausted and sealed instrumentality with atiny low amount of operating fluid. One finish of the instrumentality is given waste heat from the supply, inflicting the containing liquid to vaporize by gaining the heat energy of vaporization. The vapour flows to the cold finish of the instrumentality wherever it condenses. Since the heat energy of evaporation is far larger than the wise heat capability of a fluid, considerable quantities of heat is transported exploitation these devices with awfully tiny finish to finish temperature distinction. For evaporator lower than the condenser configuration the come of the atmospheric phenomenon is motor-assisted by gravity e.g. gravity aided heat pipes or thermosyphons. Whereas for the condenser configuration lower than evaporator or horizontal (both at same level) configuration, porous structure is marked on the inner circumference of the heat pipe to push capillary pumping of the operating fluid.

[1]Shouguang Yao, Lin Lei1, Jiangwei Deng, Sheng lutetium and dynasty Zhang studied a replacement variety of heat pipe has been developed during this study from the mix of porous copper foam exploitation 3 Nano fluids comprised of 3 sorts of nanoparticles, A12O3, CuO, and SiO2. Effect of things, like nanoparticles, filling magnitude relation, and mass concentration, on the heat transfer performance of the heat pipe were investigated. the HT improvement of the CuO nanofluid heat pipe was the most effective, followed by Al2O3 and so SiO2. Therefore, considering the 2 factors of stability and thermal physical phenomenon thought of, A12O3 nanofluids were thought of the best one and studied during this study.

[2]Shwin-Chung Wong, Ya-Chi atomic number 67 visual image experiments are conducted to research the evaporation characteristics within the nanoparticle-laden mesh-wick evaporator of heat pipe with water because the operating fluid. In one case, associate quantity of 0.01 g metallic element nanoparticles is work within the evaporator; in 2 different cases, 0.8 g nanofluid severally containing 0.01 g (0.31 vol%) or 0.04 g (1.25 vol%) Al2O3 nanoparticles is stuffed into the heat pipe. The tests are conducted because the Al2O3 nanoparticles have sedimented. The evaporation method of nanoparticle-laden mesh wicks is analogous thereto of mesh wicks while not nanoparticles. With increasing heat load, the liquid layer step by step recedes and also the evaporator resistance decreases to a minimum worth before an increase in response to the prevalence of native dry move into the evaporator. all told the take a look at cases, the evaporator seems quiescent with no nucleate boiling discovered.

[3] Kempr R. ewing D., Ching. Studied to work out the impact of the number of mesh layers and quantity of operating fluid of copper–water heat pipes which is having screen mesh wick on the heat transfer performance. It had been observed that implicit thermal resistanc decrease with a rise in heat flux, associated approaches an roughly constant worth at higher heat flux. there's atiny low increase in thermal resistance of the heat pipe once the thickness of the wick is accrued, however this can be considerably smaller than that foreseen by models supported physical phenomenon heat transfer across the wick. For all emplacements, the most transfer of heat through the heat pipe accrued because the variety of layers of mesh of the wick was accrued, obviously. the heat pipes with amounts of operating fluid near that needed to completely saturate the wick performed equally. Heat pipes with considerably less operating fluid had somewhat lower implicit thermal resistances, however the most heat transfer rate was considerably reduced.

[4]Shwin-Chung Wong , Yi - Huan Kao conferred visual image of boiling / evaporation method and thermal measurements of operational horizontal clear heat pipes. the heat pipes which are consist of twolayers of copper mesh wick which consisting of one hundred and/or two hundred mesh screens, water and a glass tube because the nano/working fluid. Experimental results showing that a fine 200mesh bottom mesh layer promted nucleate boiling which have best thermal characteristics with lower thermal resistances across the evaporator and gross temperature dispersal were found low for such a wick/charge combination. below a smaller charge, partial dryout was discovered within the evaporator. below a bigger charge, liquid recession with increasing heat load was restricted and bubbles grew and burst violently at high heat masses. the consequences of various wicks and fluid charges on the evaporation/boiling characteristics were mentioned.

[5]Shwin-Chung Wong and Chung-Wei ChenThe evaporation characteristics in operational flat-plate heat pipes wicked with formed grooves were by experimentation studied. 3 totally different operating fluids were investigated employing a groove wick and a groove-powder wick. With increase of heat load, the behavior of the fluid within the grooves was pictured, and also the physical change resistances were measured below thermally stable things For all the 3 fluids, steep-sloped liquid fronts suddenly appeared at a particular position within the heated zone higher than a particular threshold heat load. With incremented heat masses, the liquid fronts step by step receded out of the heated zone, and also the base plate temperatures and also the physical change resistances accrued at the same time below thermally stable operation, freelance longitudinal oscillations existed in

most grooves, exhibiting a perpetually varied zigzag line. Weaker periodic motion and shorter oscillation distances were discovered for water.

[6] Xue Fei Yang, Zhen-Hua Liu and Jie Zhao carried an experiment to study the heat transfer performance of a horizontal micro-grooved heat pipe using CuO nanofluid as the working fluid and shows that The heat transfer coefficients of the evaporator section can be averagely enhanced by 46% and the CHF can be maximally enhanced by 30% when substituting the 1.0 wt% CuO nanofluids for water. The heat resistance of the heat pipe decreases obviously and the maximum power of the heat pipe increases remarkably when deionized water is substituted by 1.0 wt% CuO nanofluid.

[7] Hameed H. G., Rageb a. m. carried an investigation to study the effects of nanofluid and mass of non-condensable gas on the thermal performance of variable conductance heat pipe by testing circular screen mesh wick heat pipe. The nanofluid used is water-based CuO-nanofluid with the volume fraction of 1, 3 and 5 Vol.%. The performance of the heat pipe is investigated at three different amounts of both heat input and concluded that increasing the input heat flux increases the wall temperature and the condenser active length and decreases the thermal resistance. Increasing the nanoparticles concentration reduces the wall temperature, the condenser active and the thermal resistance. Whereas, the improving in the heat pipe thermal resistance reaches to 9.5% at (Q_{in} =25 W, Ts=18.3 oC and NPC=5 Vol.%). Also indicate that the Copper Oxide nanofluid has remarkable potential as working fluid for horizontal heat pipe of higher thermal performances.

2. Properties of Nanofluid

Table 1 Properties of CuO

Concentration (wt.%)	Thermal Conductivity (W/m°C)	Dynamic Viscosity (cP)
0.5	0.618	0.799
1.0	0.627	0.801
1.5	0.645	0.802

3. Experimental Procedure

Oxygen less heat pipe designed for the experimental study together with the positions of deep-rooted thermocouples. The heat pipes consist of multilayer screen i.e. 100+150, 100+2*150 and 4*150 mesh woven copper wire as wick. 3 heat pipes were taken for testing throughout the study of this experiment. The elaborated mesh configuration of the 3 heat pipes is as tabulated. The heat pipe may be a 375 millimetre long and 39 millimetre outer diameter copper tube and each the finish sealed with end caps. One finish cap carries the filling tube for charging the operating fluid. A multi bedded copper screen mesh is inserted on tube that is 32 millimetre diameter and is command against it by tension. The Screen mesh heat pipe used consists of a sleek walled tube with a woven copper mesh because the wick structure. This wick structure is formed from a metal cloth or mesh, the mesh is wrapped around a forming arbor that is then inserted into heat pipe. Once placement, the arbor is rigorously removed jilting the wrapped mesh. The mesh get unwrap itself leaving the wick held by this tension against the inner wall of the heat pipe. The heat pipe is charged with 50 millilitre of operating fluid that more or less corresponds to the quantity needed to fill the evaporator. The operating fluid used here is water. Before charging the heat pipe is heated to a high degree, to get rid of the non-condensable gift within the tube and exhausted victimisation pump to pressure of 25 millimetre of Hg (medium vacuum). The evaporator, adiabatic and condenser sections area unit of length 100, 150 and 125 millimetre severally. Heat input was applied at the evaporator section employing a cartridge electrical heater hooked up to that with correct insulation and also the heater has been energized with associate degree AC provide through a variac. the required heat input was equipped to the evaporator finish of the heat pipe by adjusting the variac. vessel was provided at the condenser finish to get rid of the heat from the heat pipe. The cooling condenser was wont to condense the vapor. The condenser section was cooled by cooling water. The water chilling unit was fastened at a constant temperature and a chilly bath was wont to offer cooling water

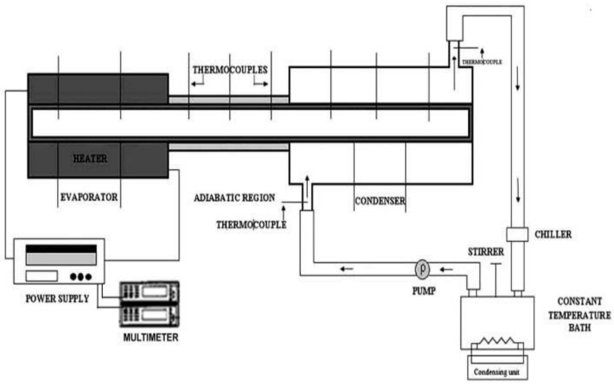

Fig.2 Heat Pipe experimental setup

Table 2 Specifications of Heat Pipe

specification	Evaporator	Adiabatic	Condenser
Heat pipe material	Copper	Copper	Copper
Length(mm)	100	150	125
Internal diameter (mm)	32	32	32
External Dia(mm)	39	39	39
Area(mm^2)	12252.21	18379.31	15315.26
Volume(mm^3)	119459.0	179188.5	149323.82

Table 3 Wicks Configuration

Description	Value
Wick configuration	1. 100+150mesh 2. 100+2*150mesh 3. 4*150mesh
Wick material	Copper
Wick Type	Screen mesh wick
Wire diameter	0.9 millimetre

4. Mathematical Equations

1). Heat transfer coefficient:

The coefficient of heat transfer for the heat pipe is calculated by calculating thermal resistance. It is outlined as;

$$h = \frac{1}{R.A_c}$$

Where, h = heat transfer coefficient
R = thermal resistance
$Ac = 2\pi rl =$ cross sectional area

2). Thermal Resistance:

Thermal resistance is property which is associated with the standard of a temperature distinction by that object/material oppose a heat flow. The thermal resistance is one amongst the foremost necessary parameters that reflect the performance of heat pipe throughout the heat transfer tests. The thermal resistance is outlined as;

$$R = \frac{(T_e - T_c)}{Q}$$

Where, R = thermal resistance
T_e = temperature of evaporator section
T_c = temperature of condenser section
Q = heat input = V*I*, here V and *I* are input voltage and current respectively.

5. Calculations

1. Calculating thermal resistance for 4*150mesh with water as working fluid
From the observation:

$$T_e = 40°C$$
$$T_c = 39.6°C$$

R = $\frac{40-39.6}{35}$....... From equation 2

$$R = 0.00954°C/W$$

This procedure can be applicable to all remaining R values for different heat inputs, mesh configurations with water as working fluid.

2. Calculating thermal resistance for 4*150mesh with CuO as working fluid
From the observation:

$$T_e = 40°C$$
$$T_c = 37.7°C$$

R = $\frac{40-37.7}{35}$....... From equation 2

$$R = 0.065°C/W$$

This procedure can be applicable to all remaining R values for different heat inputs, mesh configurations with CuO as working fluid.

3. Calculating heat transfer coefficient for 4*150mesh with water as working fluid

$A_c = 2\pi$*19.5*375
= 45964.20 mm²
= 0.0459 m²

h = $\frac{1}{(0.0954*0.045964)}$... From equation 1

$$h = 2280 \text{ W/m}^2°C$$

This procedure can be applicable to all remaining h values different heat inputs, mesh configurations with water as working fluid.

4. Calculating heat transfer coefficient for 4*150mesh with CuO as working fluid

h = $\frac{1}{(0.065*0.045964)}$... From equation 1

$$h = 3347.10 \text{ W/m}^2°C$$

This procedure can be applicable to all remaining h values different heat inputs, mesh configurations with CuO as working fluid.

6.Result and Discussion

1. Comparison of thermal resistance for various pipes with different operating fluid:

Using water and CuO as the operating fluid the thermal resistance comparison for various heat pipes is finished in fig. 3 & 4. From this analysis it's come to understand mesh configurations with 100+150 Mesh offers all-time low resistance across the mix. The 4*150 mesh has the strongest capillary action however all-time low permeableness, whereas 100+2*150 Mesh contains a highest capillary action bottom layer still as high permeableness. The finer mesh in 100+150 mesh configuration provides sensible extent on the wall aspect and 100 mesh on the vapour aspect provides less resistance to the vapour flow rate. This attribute impact their resistance. as compared the Rmin of the 4*150 mesh can't be as tiny as that of 100+2*150 Mesh, though each have same bottom layer. The work given here investigates heat pipe with regard to one necessary parameter of screen mesh wick heat pipes, the mesh count or the quantity of openings and tries to link changes to the current parameter and mixture of various layer of screen mesh wick to benefits in performance of certain industrial applications, like the flexibility to manufacture heat pipes with screen mesh wicks with a selected temperature distinction across the wick structure or to beat most operational angles for the applying. the normal heat pipes with mould wicks or grooved wicks exhibit a decent behaviour however the temperature distinction across the evaporator and also the condenser aspect is additional. therefore from equation II, it's found that the thermal resistance will increase significantly i.e. if we tend to analyse the within of heat pipe, additional resistance implies additional resistance to the flow of liquid vapour within. therefore the heat pipe doesn’t work expeditiously. Whereas attempting out the on top of mixtures it's seen that the temperature distinction is sort of low thence the heat pipe work additional expeditiously. the heat pipe with combination of 100+150 mesh works additional efficiently than others, alongside water because the operating fluid. Even the heat pipe with CuO because the operating fluid works higher with 100+150 mesh. therefore 100+150 mesh is that the absolute best choice, instead of utilizing stacked multilayer screen mesh.

Thermal resistance for water

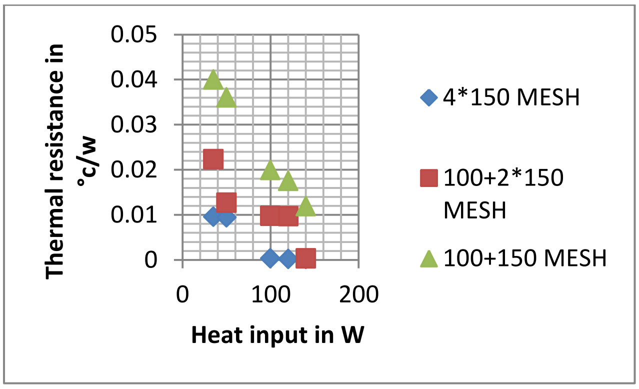

Fig.3 Thermal Resistance comparison for water as operating fluid

Thermal resistance for CuO

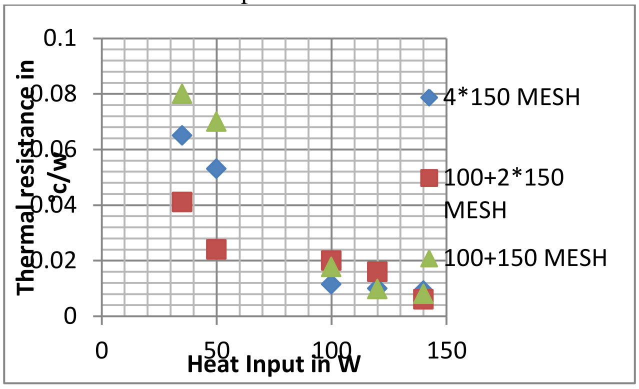

Fig.4 Thermal Resistance comparison for CuO as operating fluid

2. Comparison of heat transfer coefficient for various pipes with different operating fluid:

The coefficient of heat transfer is the reciprocal/inverse of thermal resistance within the heat pipe. The heat transfer coefficient is higher for the pipe with lower resistance. the basic in multilayer screen mesh wick pipe is that with the rise within the heat load input, the additional higher input tends to decrease the resistance, this is often owing to the actual fact that the operating fluid recedes into the menisci within the screen wicks and therefore the operating fluid gets cornered within the wicks and therefore additional a stage comes once the dryout of the heat pipe takes place. this suggests that no additional heat input applied may end in economical operating of the heat pipe. the heat transfer coefficient comparison of the heat pipes for each the operating fluid has been done as shown in fig. 5 & 6. The coefficient of heat transfer for the heat pipes with water is in higher magnitudes than that of the CuO because the operating fluid. the most comparison between the fluids is that the heat pipes with water because the operating fluid are presupposed to show comparatively terribly low resistance than CuO because the operating fluid. therefore even it's supposed that water has the best resistance as compared with the other CuO solutions, however during this case for such configurations the thermal resistance is incredibly low and high physical phenomenon too is determined

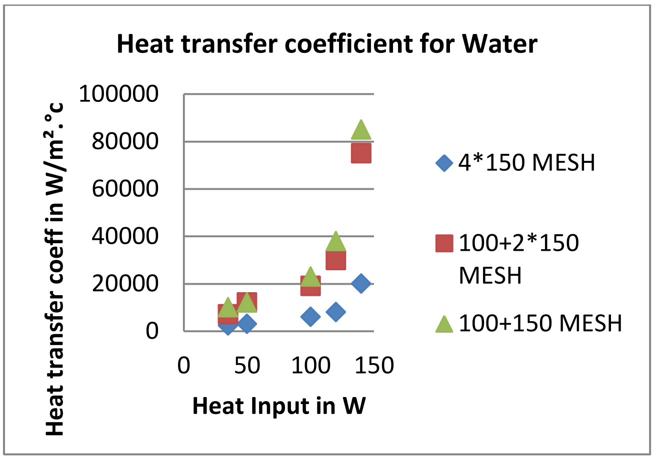

Fig.5 Heat transfer coefficient comparison for Water as operating fluid

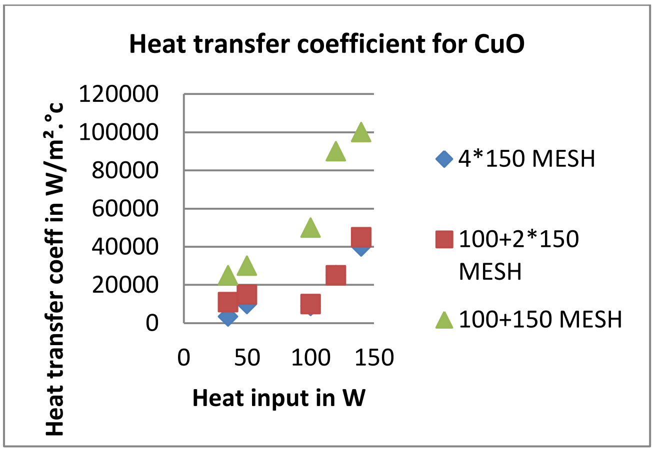

Fig.6 Heat transfer coefficient comparison for CuO as operating fluid

Conclusions

The coefficient of heat transfer of multiscreen mesh wick heat pipe is experimentally studied.

1) It is seen that the HTC for evaporator section and condenser sections increases with the increase in heat input. The addition of CuO nanoparticles within the base fluids significantly shows increase in heat transfer coefficient.
2) The maximum output is obtained by using 1.0 wt.% concentration of CuO nanofluid.
3) With increasing heat load, water film recedes into menisci among wick and therefore partial dryout happens inflicting the resistance to extend. Hence we can observe the fall of thermal resistance in the evaporator section. So finally Among three wick the mesh with 100+150 configuration gives us the better result.

References

Shouguang Yao, Lin Lei1, Jiangwei Deng, Sheng Lu and Wei Zhang, Heat transfer mechanism in porous copper foam wick heat pipes using nanofluids,International journal of heat and technology,Vol.33 (2015), No.3, pp.133-138

Shwin-Chung Wong, Ya-Chi Ho, VIsualization experiment on the evaporation characteristics in nanoparticle laden mesh wicked heat pipes, Frontiers in Heat Pipes (FHP), 4, 023001 (2013), DOI: 10.5098/fhp.v4.2.3001

R. Kempers, D. Ewing, C.Y. Ching, Effect of number of mesh layers and fluid loading on the performance of screen mesh wicked heat pipes, Applied Thermal Engineering 26 (2006), pp. 589–595

Shwin-Chung Wong, Yi-Huan Kao, Visualization and performance measurement of operating mesh-wicked heat pipes, International Journal of Heat and Mass Transfer 51 (2008) pp. 4249–4259

Shwin-Chung Wong and Chung-Wei Chen, Visualization and Evaporation Resistance Measurement for Groove-Wicked Flat-Plate Heat Pipes: Various Working Fluids and Powder-Groove Evaporator, International heat pipe symposium 10th.Nov. 6-9, 2011 pp. 41-47

X.F. Yang, Z.H. Liu, J. Zhao, Heat transfer performance of a horizontal micro grooved heat pipe using CuO nanofluid, J. Micromech. Microeng. 18 (2008) 035038.

H. G. Hameed, A-M A. Rageb, Experimental Investigation of Thermal Performance of Variable Conductance Cylindrical Heat Pipe Using Nanofluid 140706-9393-IJET-IJENSVol:14 No:06 pp. 27-32.