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ORIGINAL RESEARCH PAPER

Experimental Investigation of Heat Transfer Enhancement in a Finned U-Shaped Heat Pipe of CPU Cooling System Using Different Fluids

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ABSTRACT: This paper experimentally studies the heat absorption performance of a heat sink with vertical embedded heat pipes in the aluminium blade. The cooling system with embedded heat pipes distributes heat from the CPU to both the base plate and the heat pipes, and then transfer heat from fins to the Environment. The thermal resistance and heat transfer coefficient are evaluated for natural convection under steady state condition, by changing the heat input from 25W to 100 W. the heat pipe is filled distilled water, Ethylene Glycol, Ethanol, Ethylene glycol distilled water solution, copper oxide/ water Nano-fluid (Cu/H_2O) with different weight percentage. The results indicate that the presence of copper oxide/ water Nano-fluid in heat pipe increase heat transfer in a computer CPU cooling system and reduce the thermal resistance of the pipe rather than other fluids. In fact, use of nanofluids removes heat transfer significantly in CPU cooling systems and can be a good replacement for the common working fluid in this device.

KEYWORDS: *Convection; CPU; Computer; Cooling; Heat pipe*

INTRODUCTION

The current method to remove heat from the CPU in electronic cooling system was forced convection using a set of blade a tube with a fan install on it. However, with increased power as encountered in modern computers, the heat transfer at the CPU has importantly increased. Different methods are used to remove heat transfer from the CPU. Some researchers change the blade configuration to improve CPU performance, choi et al used circular blade configuration to improve cooling system performance[1]. In an experimental research, Kang et al[2] measure the temperature distribution in a circular heat pipe filled with silver nano-particles in pure water. The nano-particle concentrations in the range of 1 to 100 mg/l were used. The result shows temperature distribution demonstrated that the temperature difference decreased 0.56-0.65_C compared to pure water at an input power of 30-50 W. Shafahi et al[3], numerically simulated two-dimensional analysis of Nano-fluid in a cylindrical heat pipe. They showed the effect of the nano fluid with Nano-powder with a small diameter on the temperature gradient along the heat pipe. By investigating the effect of nanoparticle size and mass concentration on thermal performance, they showed that smaller particles have a more prominent effect on the temperature difference along the heat pipe. Chen[4] used silver nano-fluid in heat pipes, using this nanopsrticles in base fluid decreased heat resistance by 71%.

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Humine et al[5] made a comparison between nanfluid with 2% and 5.3% concentration with DI-water. Saeidinia et al[6], investigated the CuO-Base oil nanofluids with different particle weight fractions of 0.2-2.0. The thermal behaviour, density, heat conductivity, viscosity, and the enthalpy of the base fluid and all the prepared Nano-fluids were measured in different temperatures. they proved that the fluid's viscosity increased with an increase in weight fraction. In fact, based on these results, when enthalpy decreases, the weight fraction increases in the convection area. Sheikhkzadeh et al[7], studied the convection properties of a heat thermal wall cooled by Al_2O_3 Nano-fluid by an experimental approach. According to their obtained results, the total convection coefficient increased remarkably with Al_2O_3 particles dispersion in water, while the thermal resistance of the tube wall decreased. Mohammed Elnaggar et al [8] showed the performance of a finned U-shape heat pipe applied for desktop computer-CPU cooling. The heat resistance and heat transfer coefficient were predicted in the range of heat input 4 W to 24W.

According to t results, the inlet air velocity and the amount of imported electricity to the system have a significant effect on heat pipe convection heat transfer. T. Yousefi et al[9] Experimentally investigated the performance of CPU coolers. To improve the performance Cpu cooler, They studied the angle of inclination effect in the heat pipe and Al_2O_3 of nanofluids.

Nomenclature

			Greek Symbols
D	Diameter	K	thermal conductivity, Wm^{-2}
g	Gravitational acceleration, ms^{-2}	υ	kinematic viscosity, m^2s^{-1}
T	Temperature, K		**Subscripts**
B	Thermal expansion coefficient	e	evaporator
h	Heat transfer coefficient, Wm^2	c	cold
Nu_l	Local Nusselt number	f	fluid
Pr	Prandtl number, (υ/α)	h	hot
Ra	Rayleigh number, $(g\beta\Delta TH^3)/(\alpha\upsilon)$	nf	nanofluid

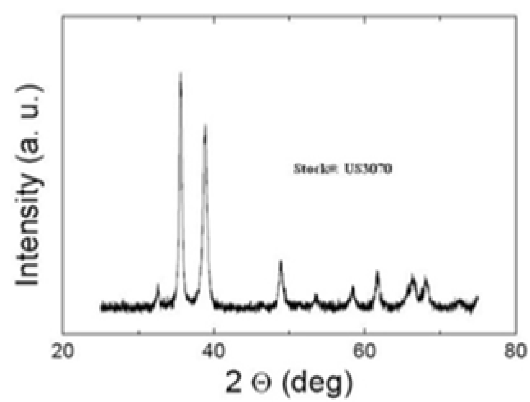
Mohammed Elnaggar et al[10], studied the blade and L-shaped heat cooling pipes in the notebook computers in a numerical and experimental approach. They founded that the amount of the inlet air, electricity and blades' area influence thermal resistance in the heat pipes.

Elnaggar et al studied the characteristics of the wick structure and working fluid of U-shape heat pipe for CPU cooling using numerical methods[11]. They showed the use of screen mesh wick caused a decrease in the pressure drop in liquid-wick region while the use of methanol as a working fluid increased the liquid pressure drop. In other research, Motahar and et all applied pured phase change material PCM and PCM with added different nanoparticles such as carbon nanofibers (CNFs) and titania (TiO_2) nanoparticles. They showed that using this new material Delay the device's arrival time to the highest temperature[12]. Teng et al completed their study on heat pipes of 8mm external diameters and 600mm length[13]. They assessed the effect of the flow congestion due to the curvature angle of heat pipe on the thermal performance of the pipes. They examined three Nano-fluid with weight diffraction of 1, 3, and 5. According to the results, they found Increasing the nanoparticle diffraction e in the heat pipe increases heat transfer by 1%. Using copper powder in welding pool surface causes a decrease in the pressure drop in the fluid area while applying methanol as the working fluid increase the pressure drop in the fluid area. In this research, the heat transfer performance of the cooling system in the computer's CPU was compared through with different fluids in four heat inputs of 25, 50, 75, and 100 watts. For the preparation of nanofluids, first the distilled water is poured into a beaker; next, slowly stabilizing sodium dodecyl sulfate of 0.1 wt% is added to the beaker. The properties of the surfactants are tabulated in Table 1 Specifications of Copper oxide nanoparticles are tabulated in Table 2.

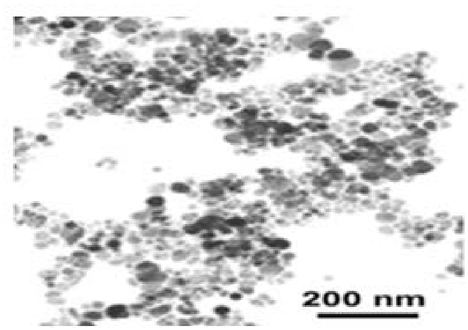
Table1
Specifications of surfactant.

Molecular formula	Molecular Weight (gr/mol)	Density (gr/cm^3)
$NaC_{12}H_{25}NO_4$	288.372	1.01

A 2.0098g magnet is put in the beaker, and the beaker is set for 10 minutes at maximum speed in order to make a ho--mogeneous solution. The copper oxide nanoparticles are added according to the weight fraction required. For homogenization of the nanofluid, it is stirred for one hour. The cupper oxide nanoparticles with a diameter of 40 nm (purity 99%) were purchased from US Research Nanomaterial, Inc (Stock: US3070, CAS: 1317-38-0). X-ray diffraction (XRD) pattern and transmission electron microscopy (TEM) image of nanoparticles were presented in Figure1[14] the properties of of Copper oxide nanoparticles are tabulated in Table 2.



(a)



(b)

Fig. 1. (a) X-ray diffraction spectroscopy copper oxide nanoparticles (b)Copper oxide nanoparticles by transmission electron microscopy

Since sodium dodecyl sulfonate form the foam in the solution, and this foam destabilizes the solvent, to overcome this phenomenon the size of the magnet must be moderated.

Table 2
Physical and thermo-physical properties of copper oxide nanoparticles.

Appearance	Black powder
Size (nm)	40
Purity (percentage)	99
Structural feature	Nearly spherical
Area ($^{m^2}/_{g}$)	20
Molecular Weight	79.55
Density($^{gr}/_{cm^3}$)	6.4
Density block($^{gr}/_{cm^3}$)	0.79
Specific heat capacity	0.54
Thermal conductivity	75

After homogenizing the solvent, the beaker is exposed to ultrasonic waves as the probe gradually reaches to the bottom of the beaker. The power and frequency of ultrasonic waves instrument are set to 60wat and 24 Hz, respectively for 90 minutes. To prevent heat decrease in the solvent, this device is run for 2 minute intervals with one-minute stoppage. After 90 minutes the nano fluid is removed from the ultrasonic wave instrument and its PH is measured. The recovered PH is 4.32 which increase to 10.05 when sodium hydroxide with 0.1 molar concentrations is added to it.

MATERIAL AND METHODS IN THE COOLING SYSTEM

Description of the U-Shape Heat Pipe

Mohammed Elnaggar et al[11], studied the fluid properties for the electric cooling system in the twin U-shaped convection pipes in the CPU, where the minimum thermal resistance in the free and force convection is 0.162 at 0.125° C and the total inlet flux is 50 watts. The excellent heat transfer performance of this vertical U-shape structure, compared with the simple horizontal heat pipe is verified. In this experiment, this model is adopted in the cooling system processor. Copper U-Shape heat pipes are usually the common pipes for Computer Processor cooling because of their high thermal conductivity, relevance, and thinness. This finned heat pipe serves to cool the CPU of a modern Pentium dual-core, Pentium five-core, Pentium eight-core with 1.86 GHz or higher processors. Here, the heat pipe is applied to transfer heat from the CPU to the fins in a remote location, usually at the sides or corners of the notebook PC. The finned flat heat pipe consists of a copper base plate of size 3.5 × 3.5 mm and condenser section of 87-mm long, with 38 aluminum rectangular fins of 90 × 3.5 mm size, Figure1. The system is supported by a radial fan of 90 × 90 × 2.5 mm width, length and thickness. The geometry of the heat pipe is tabulated in Table 3.

Table 3
Heat pipe geometry and fluid properties.

Characteristic	Dimensions/Material
Evaporator length *Le*	35mm
Condenser length *Lc*	170mm
Adiabatic length *L*ad	100mm
Original diameter	6mm
Heat pipe container thickness	0.5 mm
Wick thickness	0.5 mm
Working fluid	water, Ethylene Glycol, Ethanol, Nano-fluid water-oxide copper for weighted 0.1%, 0.3%, 1%
Wick structure	Sintered copper powder
Material of pipe	Copper

Experimental Setup

The processor cooling system, the different data acquisition system (four-channel) and the thermocouples (K-type) are used in this setup. The heat transfer surface of the heat source is attached to the lower part of the base that is mounted vertically. The temperature measurements are observed and recorded by a data acquisition unit, using K-type thermocouple as a temperature probe. The thermocouples are attached to measure the temperatures at the surface of the base plate (T_b), the evaporator section (T_e), the adiabatic section (T_{ad}), and the condenser section (T_e and Ton-e). The heater is powered by a regulated ac power supply. The experiment begins with a heating power ranging within 25 to100 W with increments of 25 W. Two vacuum gauges are used to control the vacuum level inside the pipe and pipe leakage Figure2.

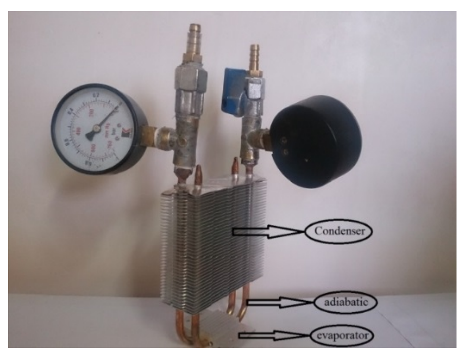


Fig. 2. Connections cooling system

The experimental setup for the finned heat pipe, consists of the finned heat pipe, fan, ac power supply applied to make the appropriate watts set by the voltage dimmer. The setup component in this study consist of: four type K thermocouples and a four-channel data logger to record temperature at any moment , a motor vacuum used to produce a vacuum condition inside the tubes in order to cycle system heat pipe, a voltmeter, an ohmmeter and a laptop to record the information, Figure3.

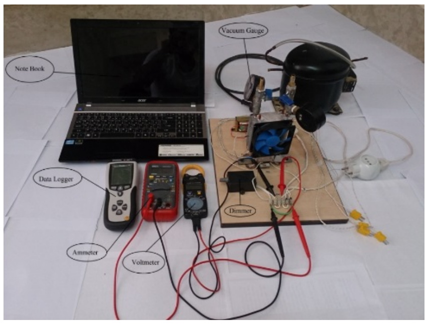


Fig. 3. Experiment components

For validation, the results of this study were compared with the data in other literature [15]. Based on the results in the Table4. It can be concluded the obtained data have a good agreement with other literature and the differences between the data are less than 3%.

To better understand the location of the test pieces, the schematic of the test is illustrated in Figure4.

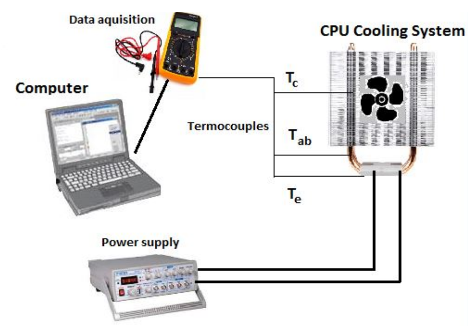


Fig. 4. Shematic of the setup

Table 4
Data validation for distilled water (along heat pipe) for 50 Watt.

Heat pipe area	Obtained data	Moradi et al[15]
Evaperator	58 °C	60 °C
Adiabatic	42 °C	46.5 °C
Condenser	39 °C	42 °C

CPU modeling

To model the computer's CPU, a heater, with maximum power of 115 watts in 3.5 × 3.5 dimensions is applied, Figure5. The heater is glued to the CPU location with silicon paste. This experiment is implemented in four heat inputs in the range of 25, 50, 75, and 100 watts.

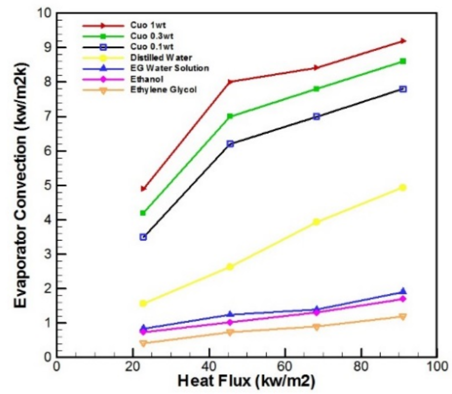


Fig. 5. Convection coefficient in evaporator

Applied fluids

Seven types of fluids are used in this research in order to reach the optimized performance of the CPU in the cooling system. In this paper, distilled water, ethanol, ethylene glycol, and ethylene glycol solution with water in equal amounts, Nano-fluid of water-copper oxide in three weight percentages of 0.1, 0.3, and 1 are applied.

CALCULATIONS

The thermal resistance of the whole pipe

In this paper, distilled water, ethanol, ethylene glycol, and ethylene glycol solution with water in equal amounts, Nano-fluid of water-copper oxide in three weight diffraction of 0.1, 0.3, and 1 are applied. The input heat transfer ratio of CPU to surround, or Q is shown. That is calculated based on terms (1a) and (1b) respectively:

$$Q = \frac{\Delta T}{R_t} \quad (1a)$$

$$\Delta T = T_e - T_a \quad (1b)$$

Where R_t, T_a, T_e are the total thermal resistance of the heat pipe, ambient temperature, temperature of evaporator, respectively. T_{ad} is the temperature of the area between evaporator and condenser, Figure3. Heat resistance of evaporator are obtained as follows [16]:

$$R_e = \frac{T_e - T_{ad}}{Q} \quad (2)$$

$$R_c = \frac{T_{ad} - T_c}{Q} \quad (3)$$

$$R_{total} = R_e + R_c \quad (4)$$

Heat transfer and heat transfer coefficient in the adiabatic section

In the adiabatic section of the tube, heat transfer is of the natural convection type which is a natural movement. To obtain a heat transfer coefficient in this part equation 5 is applied [13]:

This equation is validated for Rayleigh's number between 10^{-1} to 10^{12}. The obtained Rayleigh number for this experiment is $1.36*10^7$, so it seems reasonable.

$$NU = \left\{ 0.6 + 0.387 \left(\frac{Ra_D^{\frac{1}{6}}}{\left[1 + \left((\frac{0.599}{\Pr})^{\frac{9}{16}} \right)^{\frac{8}{27}} \right]} \right) \right\}^2 \tag{5}$$

Where, NU, Ra_D, Pr are the Nusselt, Rayleigh and Prandtl number respectively. Rayleigh number is obtained from [13]:

$$R_a = \frac{gB(T_{ab} - T_\infty)}{\upsilon^2} \tag{6}$$

Where, g, K, T_∞, ν are the gravity, thermal conductivity, ambient temperature and kinematic viscosity of the fluid, respectively. The heat transfer coefficient is obtained from[15].

$$h = \frac{K_\infty}{D} Nu \tag{7}$$

In the adiabatic part of the heat pipe, heat transfer is convection.

Equations (8-10) are used to calculate heat transfer. At a adiabatic temperature T_{ad} =41.70°C and adiabatic area A_{sd} =0.00314 The value for the heat transfer is 0.7013, which is negligible.

Table 5
Nanofluid property and heat pipe geometry.

Tube lenght	10 cm
Tube diameter	5m
K_{nf}	26.87×10^{-3} W/m.K
Pr_{nf}	26.87×10^{-3}
ν	1.749×10^{-5} m²/s
T_a	27 C°

$$T_f = (T_{ad} + T_a)/2 \tag{8}$$

$$\beta = 1/T_f \tag{9}$$

$$DL \times \pi \; A_{ad} = 4 \tag{10}$$

$$Q_{ad} = h\, A_{ad}\, (T_{ad} - T_\infty) \tag{11}$$

Calculations of the heat transfer coefficient in the evaporator and condenser

The following equations are used[15].

$$h_c = \frac{q_c}{T_a - T_c} \tag{12}$$

$$h_e = \frac{q_e}{T_e - T_a} \tag{13}$$

The heat flux in the evaporator and condenser are obtained through equations (14-15) form[15].

$$q_e = \frac{Q}{A_e} \tag{14}$$

$$q_c = \frac{Q}{A_c} \tag{15}$$

Experiment is implemented in four heat inputs in the range of 25, 50, 75, and 100 watts in the computer processor cooling system where the applied pipes are made of porous metal. By performing different experiments, the optimal amount of fluid filling in the heat pipe is checked.

Based on the data in Figure6, If up to 43% percent of the volume of the tube is filled with fluid, the temperature of the evaporator region will be reduced. But as this amount increases, the opposite effect will be generated and the temperature of the evaporator zone will increase.

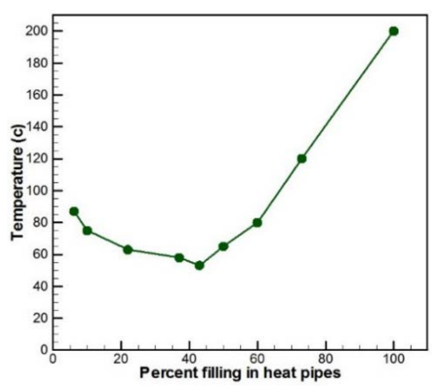


Fig. 6. Temperature Vs fluid filling percentage in heat pipe for 25 watts

Experimental Results

The temperature distribution of different positions of the cooling system at different input power of (25, 50, 75, and 100 watts) is shown in Figures (7-10) respectively. As observed in these Figs the length of the different location of the computer's processor are presented as follows: A length of 5 to 22 meters is considered for the condenser and the length of 22 to 32cm is used for the adiabatic part, 32 to 35.5 cm for the evaporator length (processor) and 35.5 to 39cm the evaporator length. There is no pressure within the heat pipe (vacuum pressure approximately -3 Psi).

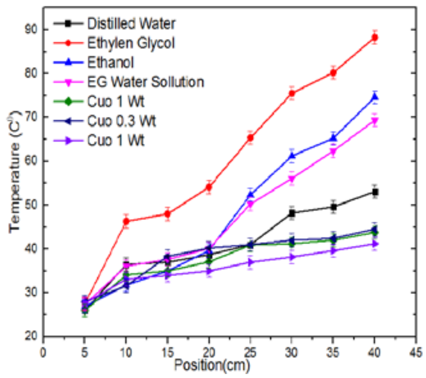


Fig. 7. Distribution of temperature along the heat pipe for 25 Watts

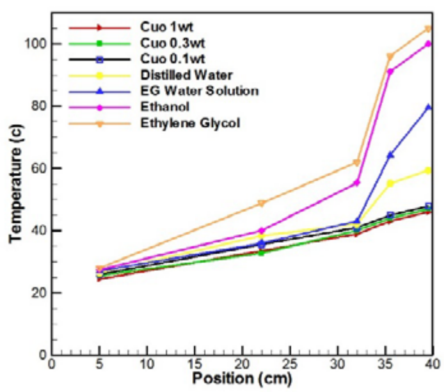


Fig. 8. Distribution of temperature along the heat pipe for 50 Watts

In fact, The difference in temperature between different fluids due to the fluid properties such as thermal conductivity and surface tension. Distilled water with nanofluids copper oxide of 1% weight diffraction keeps the processor temperature at 43°C While ethylene glycol keep the temperature about 104°C. It should be noted; the temperature difference is low (for the nanofluid) because the nanofuid with low weight diffraction is used. In high weight percentage, the temperature differences increase but The issue of sedimentation is raised.

As noted in Figures (7-10), for the ethylene glycol, ethanol and water and mixture of ethylene glycol , temperature difference varies too much during transfer from condenser to evaporator. In return when distilled water and nano-fluids are used, significant decrease is observed, which is due to the good thermal conductivity of distilled water and nano fluid.

The gentle slope from the condenser to the evaporator shows that the evaporator temperature is close to that of the condenser, hence, an improvement in Cooling System processor efficiency is made.

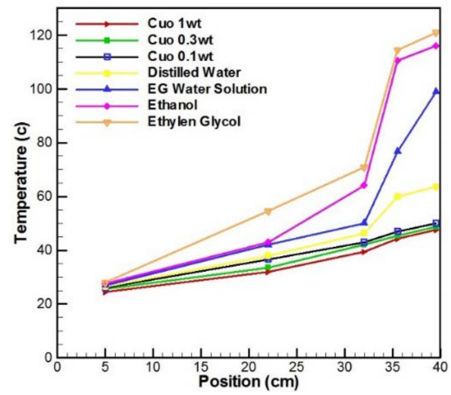


Fig. 9. Distribution of temperature along the heat pipe for 75 Watts

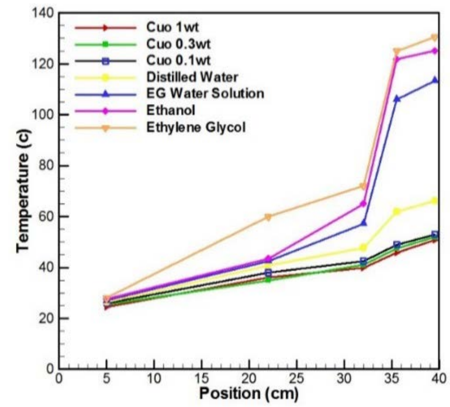


Fig. 10. Distribution of temperature along the heat pipe for 100 watts

An increase in heat transfer is observed in a mild gradient for water-copper oxide Nano-fluid . But ethylene glycol decreases the CPU efficiency due to its high boiling point. As observed in Figure10, applying water-copper oxide nano-fluid with the weight diffraction of 0.1 at 100 watts keeps the CPU temperature constant at 50.8°C, while by using other fluids temperature increase up to 130°C.

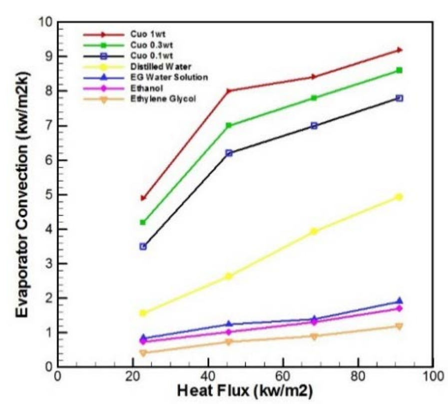


Fig. 11. Convection coefficient in evaporator

The convection heat transfer Coeficient for evaporator and condenser are presented in Figures (10-11) and these values are obtained from equation 5.

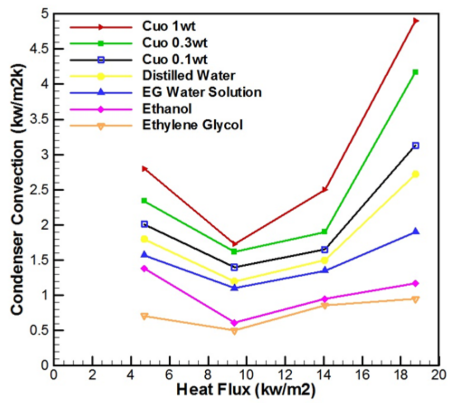


Fig. 12. Convection coefficient in condenser

As observed in Figure 10 the convection heat transfer of the evaporator increases remarkably when nano-fluid of water-copper oxide with the weight diffraction of 1% is used, Which reduces CPU temperature and increases the efficiency of the computer.

In the thermal flux q_c= 9.366, the condenser convection heat transfer coefficient decreases and this can cause desiccation in the heat pipe, Figure 11. The wick used in these pipes is porous metal. The advantage of this structure is the removal of local desiccation, This condition causes the diagram to ascend again after q_c = 9.366. The thermal resistance distribution of the heat pipe for the presented fluid in this research is shown in Figure 13.

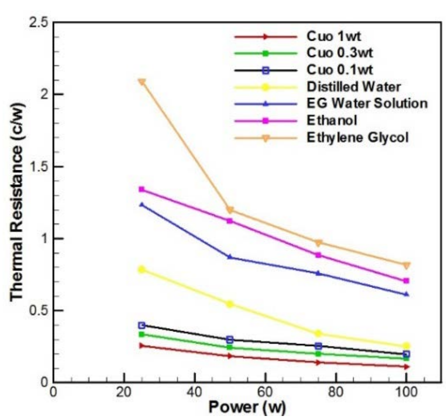


Fig. 13. Thermal resistance diagram of the whole heat pipe

It is observed that the pipe thermal resistance decreases with an increase the heat flux.

CONCLUSION

The heat transfer involved in both outside and inside the heat pipe is measured. The thermal resistance and tube heat transfer coefficient in the free convection of the entire system in four different input watts steady state, consuming fluid types like: water, ethylene glycol, and ethanol and water nano-fluids copper oxide at 0.1% weight, 0.3% and 1 were applied. Results indicated that the power input has an important effect on the total thermal resistance of the finned flat heat pipe. The optimized performance of the heat pipe in different fluid types is related to the Nano-fluid of distilled water-copper oxide with the weight diffraction of 1%, which increases the CPU temperature to 50.8°C at 100 watts. Consuming ethylene glycol in the heat pipe due to its high boiling point reduces the efficiency of the processor. The percentage of fluid filling in the heat pipe and its effect on the temperature of the heat pipe was also investigated. Based on the obtained data, the optimum percentage of fluid filling in the heat pipe was 43%.

REFERENCES

[1] Choi J, Jeong M, Yoo J, Seo M. A new CPU cooler design based on an active cooling heatsink combined with heat pipes. Applied thermal engineering. 2012 Nov 1;44:50-6.

[2] Kang SW, Wei WC, Tsai SH, Huang CC. Experimental investigation of nanofluids on sintered heat pipe thermal performance. Applied Thermal Engineering. 2009 Apr 1;29(5-6):973-9.

[3] Shafahi M, Bianco V, Vafai K, Manca O. An investigation of the thermal performance of cylindrical heat pipes using nanofluids. International journal of heat and mass transfer. 2010 Jan 15;53(1-3):376-83.

[4] Chen YT. Experimental study of silver nanofluid on flat heat pipe thermal performance. Journal of Marine Science and Technology. 2010 Oct 1;18(5):731-4.

[5] Huminic G, Huminic A, Morjan I, Dumitrache F. Experimental study of the thermal performance of thermosyphon heat pipe using iron oxide nanoparticles. International Journal of Heat and Mass Transfer. 2011 Jan 15;54(1-3):656-61.

[6] Saeedinia M, Akhavan-Behabadi MA, Razi P. Thermal and rheological characteristics of CuO–Base oil nanofluid flow inside a circular tube. International Communications in Heat and Mass Transfer. 2012 Jan 1;39(1):152-9.

[7] Sheikhzadeh GA, Nikfar M, Fattahi A. Numerical study of natural convection and entropy generation of Cu-water nanofluid around an obstacle in a cavity. Journal of mechanical science and technology. 2012 Oct 1;26(10):3347-56.

[8] Elnaggar MH, Abdullah MZ, Mujeebu MA. Experimental analysis and FEM simulation of finned U-shape multi heat pipe for desktop PC cooling. Energy Conversion and Management. 2011 Aug 1;52(8-9):2937-44.

[9] Yousefi T, Mousavi SA, Farahbakhsh B, Saghir MZ. Experimental investigation on the performance of CPU coolers: Effect of heat pipe inclination angle and the use of nanofluids. Microelectronics Reliability. 2013 Dec 1;53(12):1954-61.

[10] Elnaggar, M.H., Abdullah, M.Z. and Munusamy, S.R.R., 2013. Experimental and numerical studies of finned l-shape heat pipe for notebook-pc cooling. IEEE Transactions on Components, Packaging and Manufacturing Technology, 3(6), pp.978-988.

[11] Elnaggar MH. Numerical investigation of characteristics of wick structure and working fluid of U-shape heat pipe for CPU cooling. Microelectronics Reliability. 2014 Jan 1;54(1):297-302.

[12] Motahar S, Khodabandeh R. An experimental assessment of nanostructured materials embedded in a PCM-based heat sink for transient thermal management of electronic. Transp Phenom Nano Micro Scales. 2018 Jul 3;6(2):96-103.

[13] Teng TP, Hsu HG, Mo HE, Chen CC. Thermal efficiency of heat pipe with alumina nanofluid. Journal of alloys and compounds. 2010 Aug 1;504:S380-4.

[14] https://www.us-nano.com/inc/sdetail/222

[15] Moradi Arash, Veisi F, Y. T. Experimental Investigation of the Effect of Cu-O water nanofluid on the CPU Heat pipes. Ms thesis university of Razi, 2011.

[16] Holman J. Heat transfer. 10th. 2010, New York: McGraw-Hill.