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Experimental investigation of the effect of CuO nanoparticles on the thermal performance of heat pipe

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Abstract - In this work, thermal characteristic of a sintered wick heat pipe was examined using CuO/DW nanofluid. The study in precise emphasize on the consequence of several concentrations of CuO nano-sized particles distributed (0.5, 1.0 and 1.5 wt. %) in the base fluid; input heating power (20W-80W) and heat pipe tilt angle(0-90^0). The experiment results show that heat pipe achieve its best thermal efficiency 86.33 % at 80 W heat load and for θ=60^0 which is 26.16 % higher than DW when utilised as an operating fluid under similar operating conditions. Sintered wick heat pipe attains minimum thermal resistance at 80W, at θ=60^0. Total thermal resistance of HP at an input heating rate of 80 W when charged with 1.0 wt. % CuO, is 44.44 % lesser than DW charged heat pipe others conditions remains same.

Key words: Nanofluid, Thermal efficiency, Sintered wick heat pipe, Thermal resistance

Nomenclature			
K	Thermal conductivity W/(m K)	c/s	Cross-section
I	Electrical current (A)	vap	vapour
V	Voltage (V)	eff	effective
ṁ	Mass flow rate (kg/s)	w	Water
T	Temperature (K)	c	condenser
R	Thermal resistance (K/W)	e	evaporator
C_{pw}	Specific heat at constant pressure J/(kg K)	vol.%	Volume percentage
θ	Inclination angle (^{0})	wt.%	Weight percentage
A	Area (m^2)	DW	Distilled water
ΔT	Temperature difference (K)	HP	Heat pipe

I. INTRODUCTION

Large amount of heat is released in microelectronics devices like laptops, high computer systems, mobile telephones, semiconductors, digital chips etc. when electrical energy is given to a system to accomplish a specific task; as increasingly functions are brought in a small space [1]. Owing to this amplified energy density in digital devices it has come to be important to manipulate the thermal energy released to protect the devices from irreparable harms. For cooling of device in which there may be an obstacle of area, coolant heat pipes are best used and outside pumping required as heat pipe does not need any outside pumping for coolant flow and the cooling is caused by way of the evaporation of the operating fluid that is confined inside the evaporator phase of the heat pipe in a completely small amount. Applications of heat pipes are emphasised on fuel, energy savings and environmental protection.

Do et al. [10] using copper heat pipe having aluminium oxide as nano fluid with varying concentration; they found that thermal performance of HP with the use of nano particles was enhanced. Further Wang et al. [18] examined the effect of water based CuO NF with varying concentrations 0.5 wt. %, 1.0 wt. % and 1.5 wt. %, found that at 1.0 wt. % and for 45^0 tilt angle highest heat transfer capacity of heat pipe raised by 40 %. Kole et al. [19] conducted an experiment to study the effect of CuO nano fluids at different concentrations, heat input rate and different inclination angle on the cylindrical heat pipe and results showed enhancement in thermal performance and decline in thermal resistance was noted. Ghanbarpour et al [21] performed experiment with Al_2O_3-water based Nano

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fluids and with varying concentrations of 5 wt. % and 10 wt. % and found that thermal performance of heat pipe declined with 10 wt. % and rises with 5 wt. % as compare to water. Venkatachalapathy et al. [22] conducted experiment with CuO/Water NF for various concentrations and for various inclination angle and heat input. They concluded that maximum enhancement in thermal efficiency was 32.9 % at 140W as compared with 20 W heat input. Nikkam et al. [23] found that nano particles and tilt angle have remarkable influence on thermal performance of screen mesh heat pipes and at 60^0 tilt angle lowest thermal resistances obtained. Maximum heat transfer efficiency increased by 29 % as compare to water. Ramachandran et al [25] examined the effect of hybrid nano fluids ($CuO+Al_2O_3$) in heat pipe (screen mesh wick) with 0.1 vol. %. They found 44.25 % reduction in thermal resistance as compared to DW. Aly et al. [8] evaluated the thermal performance of a helically grooved pipe with Al_2O_3 and water as working fluid at various inclination angles and for various filling ratio. They found that thermal performance increased as filling ratio increases and thermal resistance decreased by 18.2 % as compare to water. Cheng et al. [9] studied the effect of gradient wettability inside grooved heat pipes and found that by fabricating gradient wettability thermal performance of heat pipe enhanced and thermal resistance decreased. Sarafraz et al. [13] studied experimentally efficiency and the thermal performance of a copper thermosiphon pipe filled with Alumina–Glycol based nano fluids at different concentrations varying from 1-5 vol. % and found that for 5 vol. % the maximum decreased in thermal resistance found to be 22.63 %. Nazarimanesh et al. [31] found experimentally the impact of different tilt angle and various heat input rate on sintered heat pipe filled with silver nano particles of concentrations 0.001, 0.005, 0.1 vol. % and determined thermal resistance of heat pipe reduce to 42.26 % as compare to base fluid. Mehrali et al. [33] did experiment to find the effect of GNP nano particles concentrations, different heat input rate and tilt angle on the sintered wick heat pipe and found that thermal resistance decreased up to 48.4 % as compare to base fluid.

Table 1.Summary of literature studies of heat pipes

Researcher	Operating fluid	Concentration of Nanofluid	Specimen	Thermal performance improved
Do et al. [10]	Al_2O_3/water	1.0, 3.0 vol.%	(O.D.-4 mm, L-300 mm)	65 %
Wang et al. [18]	CuO/water	0.5wt. %, 1.0wt. %, 1.5wt. %	(O.D.-8 mm, L-350 mm)	40 %
Kole et al. [19]	Cu/water	0.0005, 0.005, 0.05, 0.5 wt.%	(O.D.-10 mm, L-300 mm)	15 %
Nikkam et al. [23]	SiC/Water	0.35wt. %, 0.7wt. %, 1.0wt. %	(O.D.-6.35 mm, L-250 mm)	30 %
Yousefi et al. [27]	Water/Al_2O_3	0.5 wt. %	(O.D.- mm, L-120 mm)	24 %
Sarafraz et al. [13]	Alumina–Glycol	0.1-0.4 wt.%	(O.D.-12 mm, L-280 mm)	22 %
Aly et al. [8]	Al_2O_3/water	3.0 vol.%	(O.D.-15.87 mm, L-550 mm)	18.2 %

After studying the literature of heat pipes, it has been concluded that various investigations have been conducted with a view to investigate and the performance of heat pipes mainly in definite circumstances and constrained positions [28]. Most of the earlier investigation has been executed for mesh wick HPs. Slight work has been carried out on sintered wick heat pipe, although it generates decent capillary action inside the heat pipe [34]. The present study emphases on the use of sintered heat pipe with varying concentration of CuO nanofluid, various pipe inclination angle with horizontal axis and for various heat input, and compare this work with water as operating fluid.

II. EXPERIMENTAL PROCESS

1.1. Nanofluid Synthesis

The nanoparticles used in this study are CuO. The shape of the nanoparticles are spherical. To weigh the CuO nano-sized particles for mass concentrations of 0.5 wt. %, 1.0 wt. % and 1.5 wt. % a digital milligram scale of high precision is used. After that CuO nano-sized particles are suspended in DW by two step method and the solution is mixed by magnetic stirrer.

2.2 Experimental set up and test procedure

The apparatus used in this experiment are as: sintered wick heat pipe, heating and cooling unit, K-type thermocouples, a thermostat unit, a data acquisition system and voltmeter and ammeter.

Table3: The heat pipe used in this experiment has following parameters;

Parameters	Dimension (mm)
Diameter	12
Wall thickness	0.5
length	300
Wick thickness	1

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In order to remove trapped oxygen and other gases from heat pipe vacuum pump was used; all pipes were evacuated, and then charged with equal quantities (filling ratio) of operating fluid. There are three segments of heat pipe i.e. condenser, evaporator and adiabatic segments each having length of 100mm. In this experiment we have taken 4 heat pipes i.e. first charged with DW, second with 0.5 wt. % of CuO/DW, Third with 1.0 wt. % of CuO/DW and fourth and last one with 1.5 wt. % of CuO/DW.

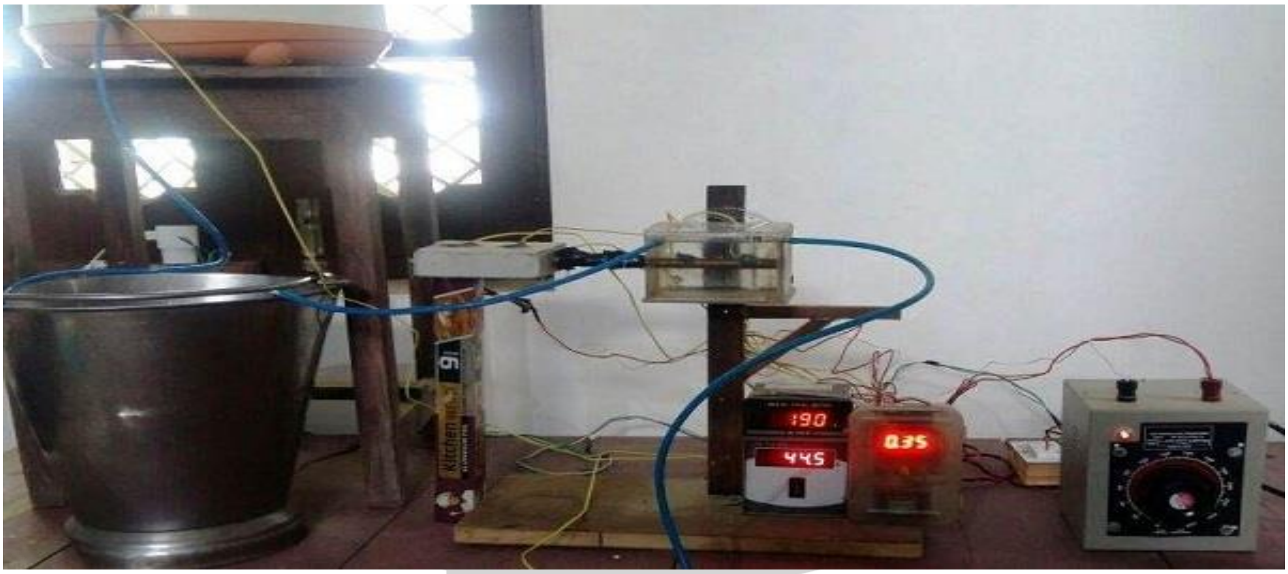

Fig.1 Physical view of experimental set up

A heating element is attached to the evaporator section i.e.100 mm in length. For uniform heating of the heat pipe we have taken an aluminium block of 100mm×80mm×10mm in dimension. This block is equipped with two electrical and cylindrical heaters dissipating 60W each and this block is completely covered with asbestos material to prevent heat loss to the surroundings. To improve the thermal conduct a thermal paste is used between the sintered heat pipe and the aluminium block. A control variable auto transformer is also attached with this to control the heat input rate. The specifications of variable transformer (MADE IN INDIA) are as; inputs 240 volts 50-60Hz and output 0-270 volts and 2 ampere maximum current. The middle section of the pipe of 100 mm is known as adiabatic section. This section is shielded with aluminium foil, glass wool and Teflon tape to prevent the heat loss to the atmosphere.

Fig.2 Sintered wick heat pipe used in experiment

To evaluate the wall temperature of pipe six thermocouples (K-type) are mounted on HP. Two thermocouples have mounted on evaporator, first at a distance of 20 mm (T_1) and other at a distance of 70mm (T_2) from the evaporator section. Two thermocouples are fixed on adiabatic, one at a distance of 130 mm (T_3) and other at a distance of 170mm (T_4) from the evaporator section. Two thermocouples are fixed on condenser, one at a distance of 230 mm (T_5) and other at a distance of 270mm (T_6) to the evaporator segment. For the measurement of the inlet temperature of cooling water one thermocouple (T_7) is attached to the inlet of the condenser segment and another for the measurement of the outlet water temperature (T_8) at condenser section. Before the experiments all the thermocouples are calibrated. To measure the given voltage we use digital panel meter (*M-TECH INDIA make*), range of this voltmeter is 0-240 V. To measure incoming current ammeter has been used. A *NUTRONICS data acquisition unit* is used in order to monitor all the temperature values with 12 inlet port for the attachment of thermocouples. For the cooling of condenser section of heat pipe we make a block of 12×8×8 mm^3 of acrylic fibre then for the circulation of water one inlet and one outlet port is given. To keep the inlet temperature almost constant (~23^0 C) we attach a thermostat unit. The circulation of water in condenser section is assisted by gravity so there is no need of pump for water circulation. To measure the flow of inlet water we use flow meter and keep the flow rate constant at 300ml/min.

2.3 Data reduction

In this experiment four heat pipes charged with CuO/DW and DW as operating fluid are tested for different tilt angles and heating input power.

Thermal resistance of the heat pipe is given by:

$$R=\frac{T_e-T_c}{Q} \qquad (1)$$

Here, Q=heat input rate (V), T_e= Evaporator's Wall temperature, T_c= Condenser's Wall temperature

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Where temperature difference of the evaporator,

$$\Delta T_e = T_e - T_{vap} \quad (2)$$

Also, $T_e = \frac{T_2 + T_1}{2}$

$$T_{vap} = \frac{T_4 + T_3}{2}$$

$$T_c = \frac{T_6 + T_5}{2}$$

Where T_{vap}= wall temperature of adiabatic section and we also take this temperature equals to the vapour temperature of the working fluid because heat pipe's wall surface resistance is negligible. (~10^{-3} ^{0}C/W)

Effective Thermal conductivity is calculated from:

$$K_{eff} = \frac{L_{eff}}{A_{c/s}R} \quad (3)$$

Where, A_c= area of cross-section of heat pipe

$$L_{eff} = 0.5L_{evaporator} + L_{diabatic} + 0.5L_{condenser} \quad (4)$$

Thermal effectiveness of cylindrical heat pipe is given as:

Mathematically, $\eta_0 = \frac{Q_c}{Q} = \frac{\dot{m}C_{pw}\Delta T_w}{VI}$ (5)

Here, Q=Heat given to evaporator, Q_c=Heat removed by cooling water, C_{pw}=Cooling water's specific heat, $\dot{m}$=Cooling water's mass flow rate, ΔT_w= rise in the cooling water temperature

III. OUTCOMES AND DISCUSSION

In this experiment sintered heat pipes were tested with different concentrations of CuO/DW nanofluids at different heating input loads and for several tilt angles. The suspended nano particles improve heat transfer features and the heat transport properties of the working fluids in heat pipes effectively.

3.1 Influence of various factors on the heat pipe wall surface temperature:

Fig.3 (a-d) indicates the surface temperature of wall of heat pipes for various heating loads, inclination angles and for different concentrations. At 100W heating input load, heat pipe charged by DW as operating entire fluid gets vaporised and dry out conditions occurs for all situations of heat pipe. This difference of temperature increases from $\theta=0^0$ - 60^0 and decreases as further $\theta=60^0$ - 90^0. This concludes that inclination angle strongly affects the heat pipes wall surface temperature. Figs.3-4 illustrate surface temperature of a sintered heat pipe charged by different nanofluid concentrations for heat load of 20W and 80W. The results reveal that the surface wall temperature of HP is lower when charged with CuO nanofluid than when charged with DW. For example, Fig.3 (a) shows that for $\theta=0^0$ and a heat load of 20W, that the surface wall temperature of HP charged with 1.0 wt. % concentration of CuO nanofluid is 9.55 C^0 than when heat pipe is charged with DW. But at the same conditions for $\theta=90^0$ wall surface temperature is 7.20 C^0 lower for CuO 1.0 wt. % than when using DW as operating fluid.

Fig.4 illustrate reduction in the surface temperature as concentrations of CuO nanofluid increases in base fluid but the overall thermal effectiveness of HP is increased. However, surface wall temperature rises as the input heating load rises from 20W to 80W. Fig.4 displays for $\theta=0^0$ and a heat load of 80W, that the surface wall temperature of HP charged by 1.0 wt. % concentration of CuO nanofluid is 39.9 C^0 than when heat pipe is charged with DW. But at the same conditions for $\theta=90^0$ wall surface temperature is 35.9 C^0 lower for CuO 1.0 wt. % than when using DW as working fluid. By comparing Figs.3-4 it is observed that surface wall temperature is more affected by nanofluid concentrations rather than input heating load to evaporator.

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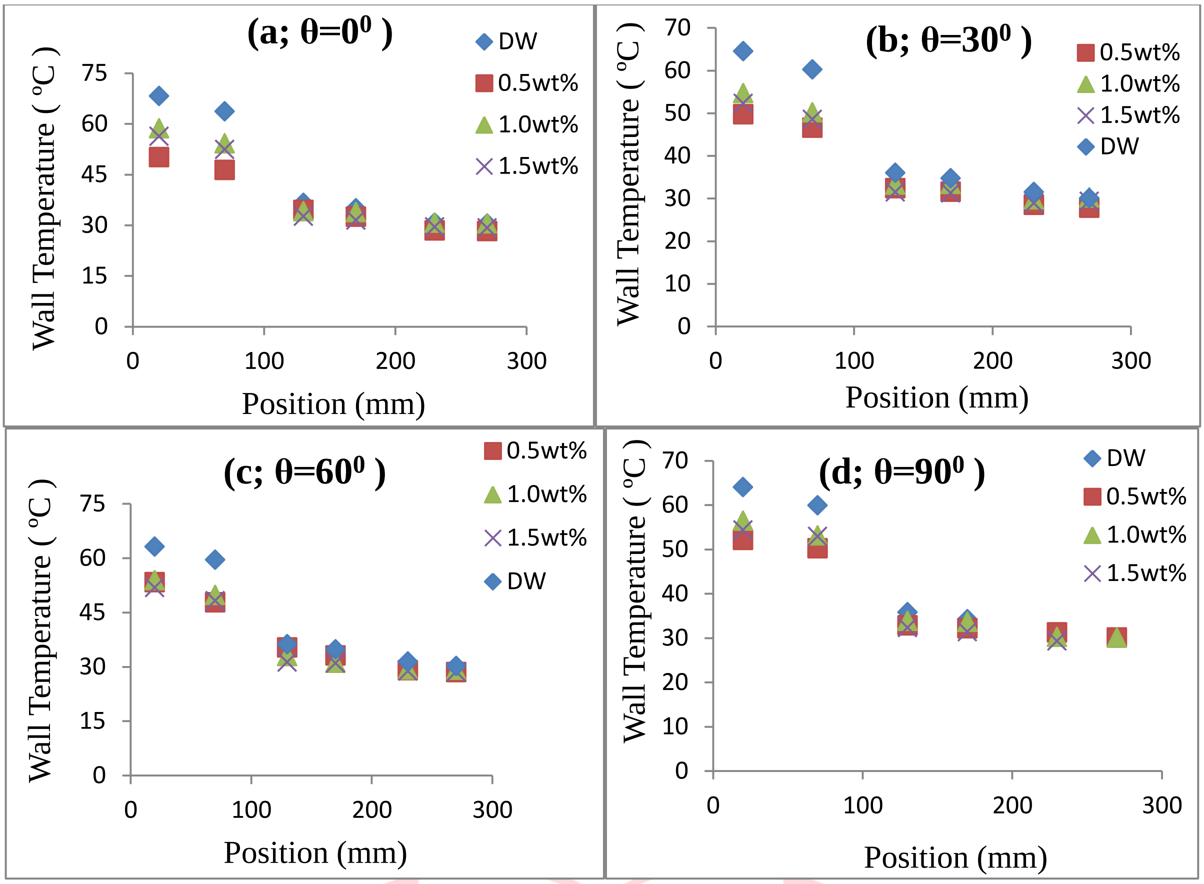

Fig.3 (a-d) Distribution of wall temperature at various tilt angles for 20W

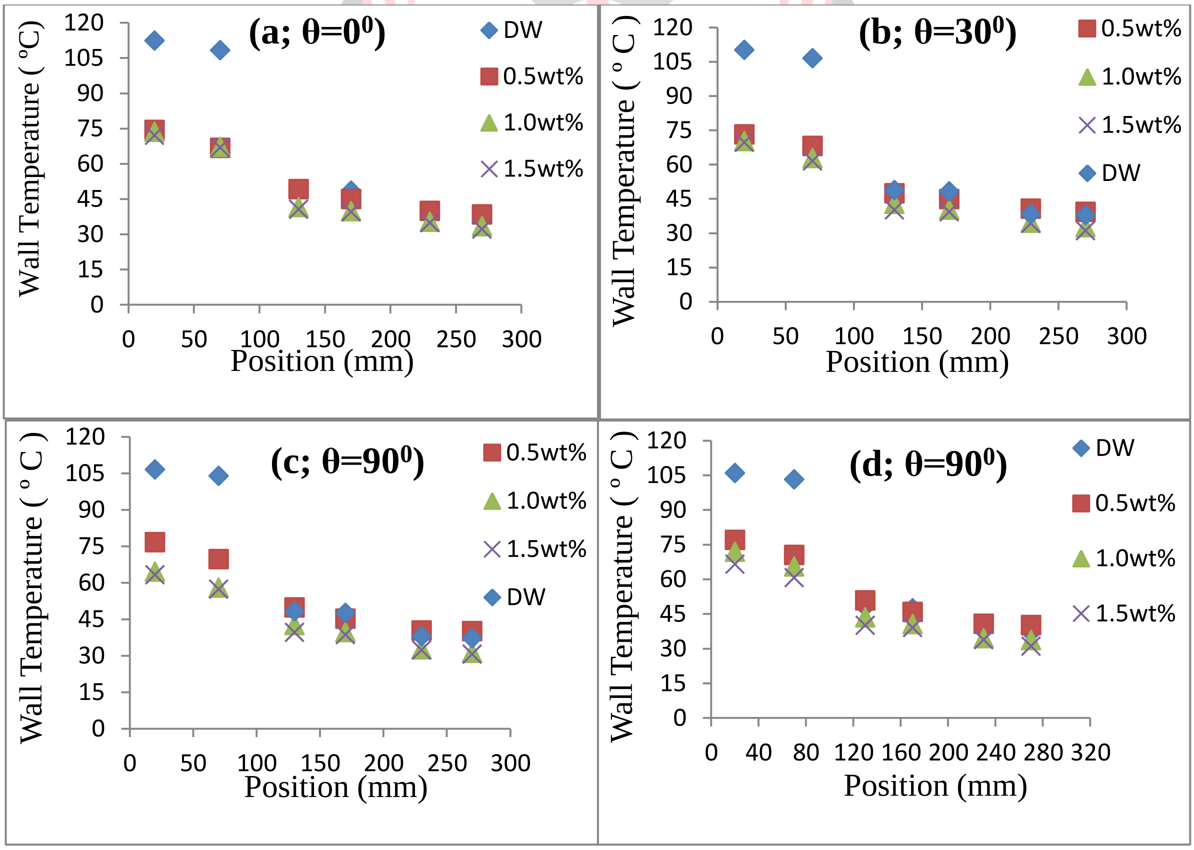

Figure.4 (a-d) Distribution of wall temperature at different tilt angle for 80W

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3.2 Efficiency of heat pipes:

Fig.5 illustrates the thermal effectiveness of HP's for several heat inputs and for various tilt angles of heat pipes. Results shows that with the increment in input heating load the resistance of the pipe decreases and as heating input rate increases, increases in the efficiency of heat pipe also noticed. The tilt angle of HP from horizontal position also has a major impact on thermal efficiency, up to θ=60° its efficiency increases progressively and after this it starts decreasing. Generally, the vapour movement starting off the evaporator segment to condenser is primarily because of difference in density; however condensed fluid come back towards evaporator segment is caused by the collective result of capillary pressure of sintered wick structure in heat pipe and gravity. Up to θ=60° the fluid flow rate also increases due to gravity from condenser to the evaporator segment, whereas above θ=60° tilt angle the heat supply to evaporator segment is insufficient. This give rise increment in the thermal resistance of HP as decline in heat transfer in radial direction. In this experiment heat pipe achieve its best efficiency 86.33 % at 80 W heat load and for θ=60 which is 26.16 % higher than DW when used as a working fluid conditions remains same.

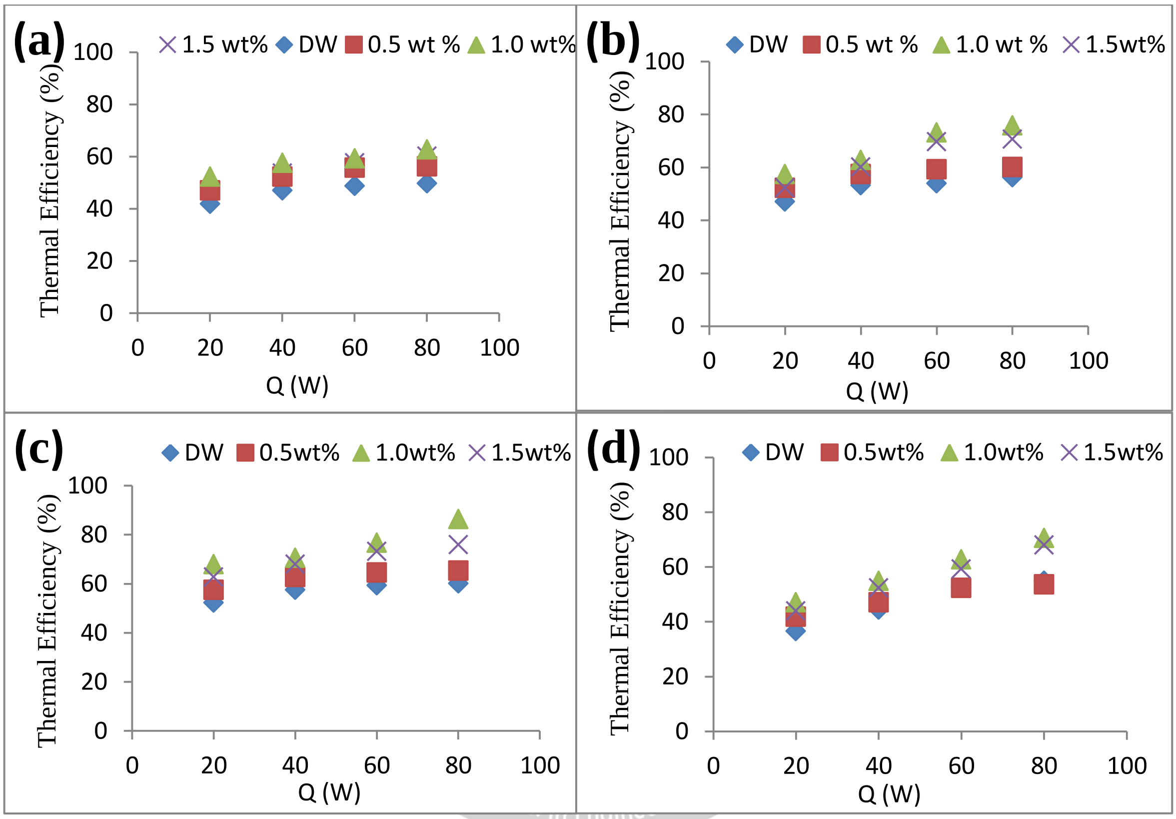

Fig.5 Thermal efficiency of heat pipes at various inclination angles (θ): (a) 0° (b) 30° (c) 60° (d) 90°

3.3 Influence of various selected parameters on thermal resistance of heat pipes

Figure.6 illustrate the influence of CuO concentrations in the operating fluid and heating input rate to the HP on overall thermal resistance of sintered HP, using CuO and DW as operating fluid. At low heat input rate the overall thermal resistance of sintered wick HP's is high and reduces as input heating rate increases while thermal resistance of sintered wick pipes reduces as we increase the concentrations of nano-particles in base fluid up to 1.0 wt. % after that starts increases.

Furthermore, Figure.6 illustrate that the thermal performance of heat pipe is not much effected by the inclination angle. This implies if gravity is solely operational constraint then HP ought to have best performance at vertical position i.e. $\theta=90^0$. However in this investigation heat pipes shows its best thermal performance at a tilt angle of $\theta=60^0$ .Heat pipe attains minimum thermal resistance at 80W and at an angle for $\theta=60^0$.Total thermal resistance of HP when charged with 1.0 wt. % concentration of CuO/DW and input heating rate of 80 W, is 44.44 % lesser than DW charged HP others conditions remains same.

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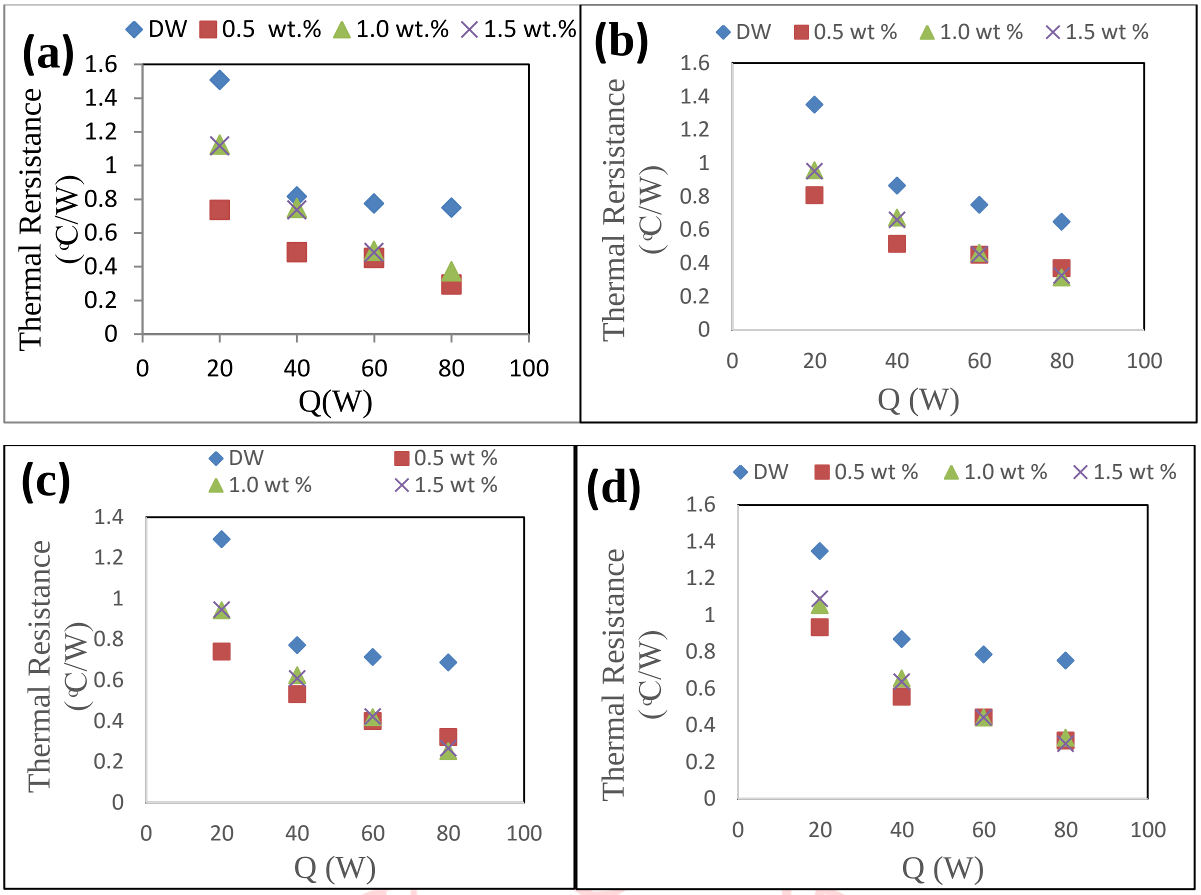

Fig.6 Thermal resistance of heat pipes at various inclination angles (θ): (a) 0° (b) 30° (c) 60° (d) 90°

3.4 Heat pipe's effective thermal conductivity

At isothermal conditions heat pipe can transfer enormous quantity of heat that is why heat pipe is used in many heat producing devices. Heat supply rate is affected by the thermal conductivity of the operating fluid; hence heat pipe's effective thermal conductivity is affected too. Therefore nano-particles dispersion in base fluid can considerably increase the thermal conductivity of operating fluid in addition to sintered HP. Figure 7 illustrate the changes in thermal conductivity of HP at various heat low, for various concentration of nanofluid charged and for various heat input rate. By the increment in CuO concentration and heat input rate effective thermal conductivity is seen to be increase. Heat pipe shows lowest thermal conductivity, k = 1173.65 (W/Km) at horizontal position for DW, while highest thermal conductivity, k =4037.8 (W/Km) is obtained at 60^0 inclination angle for concentration of 1.0 wt. % of CuO/DW at a heat input rate of 80W.

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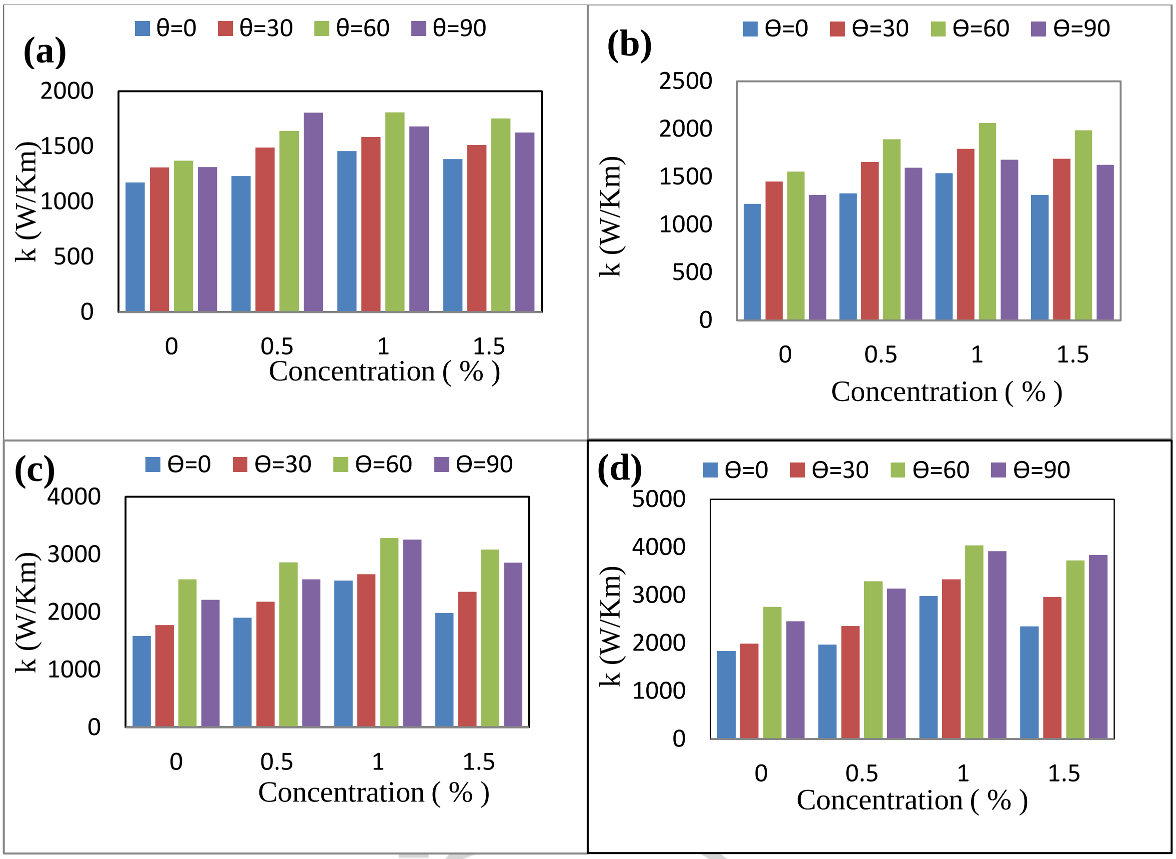

Fig.7 Effective thermal conductivity of heat pipes (sintered wick) for different heat input rates: (a) 20 W, (b) 40 W, (c) 60 W, (d) 80 W.

IV. CONCLUSIONS

The thermal characteristics and ability of heat transfer of sintered HP is experimentally examined then compared with various concentrations of CuO nanofluid (0.5 wt. % to 1.5 wt. %) and DW for various input heat rate and various inclination angles. From this experiment surface wall temperature, thermal resistance, thermal efficiency and effective thermal conductivity are obtained. It can be concluded that: At an input load of 80W, for 1.5 wt. % concentration of CuO and at 60^0 inclination angle the highest decline in surface temperature is found to be 42 ^{0}C.The heat pipes shows its best thermal enactment at a tilt angle of $\theta=60^0$. Heat pipe attains minimum thermal resistance at 80W and at an angle of $\theta=60^0$.Total thermal resistance of HP when charged with 1.0 wt. % concentration of CuO and input heating rate of 80 W, is 44.44 % lesser than DW charged heat pipe others conditions remains same. In this experiment heat pipe achieve its best efficiency 86.33 % at 80 W heat load and for θ=60 which is 26.16 % higher than DW when used as a working fluid conditions remains same. Heat pipe shows lowest effective thermal conductivity at horizontal position for DW, while highest is obtained at 60^0 inclination angle for concentration of 1.0 wt. % of CuO/DW at a heat input rate of 80W.

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