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Enhance the Thermal Performance of Heat pipe using Copper Oxide (CuO) as Nanofluid

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Abstract: Heat pipes are passive heat transfer devices, it transfers heat by evaporation and condensation of working fluid partially filled in it. Heat pipe are passive heat transfer devices, it transfers heat by evaporation and condensation of working fluid partially filled in it. Thermal performance of the heat pipe with mesh type wick and charged with copperoxide nanofluid is studied and compared with that of De Ionised (DI) water as base fluid. The heat pipe filled with CuO nanofuid and DI water is evaluated for the heat supply range of 40 –200 W. The effects of inclination angle, heat input and mesh type wick structure on the thermal performance of the heat pipe are investigated. Due to the mesh type wick, heat transfer coefficient improves up to 43% at the inclination angle of 45° for the heat supply of 40-200W. Also, thermal resistance of the heat pipe is reduced by 20%, 30% and 24% respectively for horizontal, inclined and vertical positions when compared to the water as base fluid in heat pipe. Thermal performance of heat pipe increases with CuO as nanofluid compared to based fluid (DI water).

Key words: Heat pipe, Mesh type wick, CuO nanofluid, De Ionised Water, Electronic Cooling.

1. Introduction

Heat pipe is a passive heat transfer device, it's widely used in various heat transfer applications. Due to the phase change principle, a substantial increase in thermal conductivity is observed. So that thermosyphon (TPCT) a highly used apparatus in a various of thermal engineering applications such as solar power systems, electronic cooling, heat power recovery, heating ventilation and air conditioning system(HVAC) and aerospace engineering [1–3]. Heat transfer principle of evaporation of the fluid in the lower section called evaporator and moves to condenser section where the heat is taken out by cooling device. It is shown that, in the analysis of thermal systems, the lumped capacity and thermal network formation are the efficient engineering tools when the simplified models of the transient heat conduction and heat convection are sought [4–6]. Finally, the condensate returns to the evaporator as a result of gravity force.

The conventional cooling fluids (i.e water) which as low poor thermal characteristics, and also having the low thermal conductivity as compared to non-conventional fluids such as copper oxide, aluminium oxide, TiO2 etc. Instead of applying the various techniques like use of mini and micro channels and extended surfaces, there is always higher demand for improve in heat transfer rate. Because solid materials having higher thermal conductivities compared to conservative cooling fluids, many researchers carried out experimental work on thermal properties to investigate the effect of addition of suspensions of solid particles in conventional heat transfer fluids. Ahuja [7] and Liu et al. [8] conducted studies on the practical feasibility of addition of metal slurries on enhancement of heat transfer and its hydrodynamic behaviour. In early research, suspensions of millimetre(mm) or micrometer(μm) sized particles were used in working fluid it shows that significant improvement but due to large sizes of the solid particles, gives problems such as settlement of particles, scratch and blockage of channels, increase inflow resistance. Nanoscience gives advanced techniques to develope solid particles down to the nanometer size. Fluids with dispersed nano sized particles are called nanofluids [9].

In nanofluid several aspects are considered for heat transfer such as volume fraction of nanoparticles [10], particle size [11] and shape [12]. Teng et al. [13] reported an experimental study to show the role of alumina nanofluids as working fluid in a heat pipe. The experimental study gave that the effects of filling ratio, inclined angle of the thermosyphon, and nanofluid volume concentrations on the thermal improvement of the thermosyphon. Their results showed that the optimum operating form of heat pipe exits for nanofluid containing of 1.0 wt% nanoparticles. Kang et al. [14] examined the special effects of silver Nano sized particles on the thermal performance of 1 mm wick-thickness sintered rounded heat pipe. It shows that by dissolving of silver(Ag) nano-particles in base fluid of de-ionised(DI) water, wall temperature difference of the thermosyphon is decreased in comparison with the thermosyphon filled by pure water in different heat input. The thermal resistance of two-phase closed thermosyphon(TPCT) using DI water and different water based nanofluids of aluminium oxide, copper oxide and laponite clay were experimentally investigated by Khandekar et al. [15]. They investigated that by increasing of wettability and trap of nanoparticles in the grooves of the surface roughness, evaporator side Peclet number is reduced. This finally leads to a poor thermal performance.

Kang et al. [16] studied a silver nanofluid loaded heat pipe. Experimental results were obtained for two various particle sizes. It reduced 50–80 % in the thermal resistance for the particle size of 10 and 35 nm separately. Similar reduction in the thermal resistance was experimental by Liu et al. [17] in the investigation of the grooved heat pipes filled with nanofluids. Naphon et al. [18] evaluated the thermal efficiency of the heat pipe filled with titanium nanofluids. It gives that the thermal performance of the thermosyphon was increased up to 10 % for 0.01 % volume concentration when compared with the DI water as the working fluid. Ding et al. [19] calculated the heat transfer performance of aqueous suspensions of multi-walled Carbon nano tube nanofluids flowing through a flat tube. They observed 350% improvement of the convective heat transfer coefficient and this improvement depends on the Reynolds number and CNT volume concentration. For traditional nanofluids (prepared with nanoparticles without function), a deposition coating commonly procedures on the heated surface through the phase-changing heat transfer. However, for functioning nanofluid, no deposition layer is yield on the heated surface through the phase-changing heat transfer method, which promises the stability and the reliability of the operating apparatus using nanofluids as working fluids [20].

Nomenclature

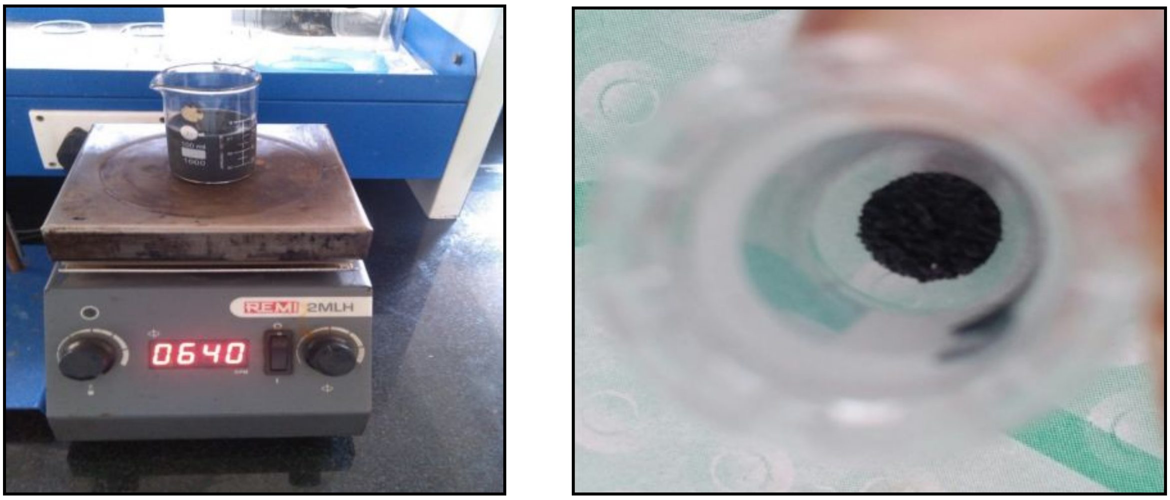
Dnf	**diameter of nanoparticle, nm**		
d_i	inner diameter of heat pipe, mm	US	Ultrasonic vibration
H	Heat Transfer co efficient, W/m2K	V	Voltage (V)
l_e	length of evaporator section, mm	I	Current(A)
l_c	length of condenser section, mm	T_e	Evaporator temperature (^{o}C)
l_{hp}	length of TPCT, mm	T_c	condenser temperature (^{o}C)
R	thermal resistance (°C/W)	T_w	water temperature(^{o}C)
		Q_{in}	Inlet heat (W)
Abbreviations			
HP	Heat Pipe		
TPCT	Two phase closed Thermosyphon		
CuO	Copper Oxide	Greek symbols	
DI	De-Ionised Water	φ	concentration of nanoparticles, vol,wt %

The main focus of this work is directed towards the effects caused when nanoparticles (i.e.copper oxide) are added to the working fluids and experienced with two phase closed thermosyphon(TPCT) ,which is compared with DI water as base fluid.We have experimentally investigated on the performance of TPCT. CuO as nanofluid (working fluid) on the cooling performance of a two-phase closed thermosiphon(TPCT). Concentrations of nanoparticle is 0.060% were prepared and applied for different input powers. The effects of heat input and the inclination angle on the performance of TPCTs are also investigated. Heat transfer performance and thermal resistance CuO in TPCT is compared with DI water.

2 Experimental details

2.1 Preparation and characteristics of nanofluid

Nanofluids are engineered colloidal suspensions of nanoparticles in base fluids. In general the size of these nanoparticles varies from 1-100nm in size. Nanofluid is produced by metal oxide nanoparticles suspended in base fluid such as DI water. The nanoparticle suspended in the base fluid should stable for long a long time. For this research CuO nanofluid is prepared by two step method. Initially CuO nanoparticle is prepared by precipitate method copper sulphate pentahydrate as precursor. Precursor is dispersed in water.Sodium hydroxide a redusing agent.it is added into precursor by droplet upto colour change.then it is heat by oven upto 200°. Copper oxide powder is prepared. Average CuO nanoparticle size (Dnf) is 80nm. At that point the molecule were blended in base liquid utilizing attractive stirrer for 3h and after that ultrasonicated (US)for a few hours to get even and stable suspension of nanoparticle. In this study no dispersant or stabilizer was as they may affect fluid properties. Even after sonication sedimentation of particles was observed, so stirrer was used during the experiment to minimize the sedimentation of CuOnano particles.



(a) (b)

Fig 1. (a) Magnetic stirrer (b) CuO nanoparticle

2.2. Test set-up and details

The trial testing setup of the heat pipe is appeared in Fig. 3.It consists of a resistance heater (1000 W), variable transformer, Wattmeter and data acquisition system. The total length of the TPCT is assumed as 350 mm. The evaporator (l_e), adiabatic and condenser (l_c) area lengths are 100, 100 and 150 mm separately.Al_2O_3 nanofluid is used as a working fluid. TPCT fenced in area was cleared and kept up at a vacuum weight of 104 mbar for around 6 h. During the vacuum pumping process, temperature of the heat pipe is kept up at 400°C so as to evacuate the non condensable gasses. After this process the vacuum line is closed by adjusting a valve and the heat pipe enclosure is cooled by ice. Then the required amount of working fluid (22ml) is charged while the vacuum line is closed. After the charging process, instrumentation is made for the execution investigation. After the instrumentation, heating element connected with variable transformer and wattmeter are used to apply a controlled heat input at the evaporator of heat pipe. The LXI Data Acquisition/Switching Unit (Agilent-34972A) is used to record the thermocouple signals. After the charging process, instrumentation is made for the execution examination. After the T-sort thermocouples (OMEGA) with a precision of±0.1°C are utilized to record the temperature readings. The delta and outlet temperature of the cooling water are likewise recorded.

The whole evaporator and adiabatic segment of the heat pipe is protected with 4 cm thick fibre glass material to keep away from warmth misfortune to the environment.

Fig 2. The experimental testing setup of the Heat pipe

A cooling coat with channel and outlet ports is manufactured utilizing the acrylic funnel. At the condenser, cooling water with a consistent stream rate of 420ml/min is supplied with steady temperature of 15°C.The exactness of thermocouple incorporating the instability in the information logger is ±0.2°C. The instabilities in the estimation of temperature and stream rate are ±0.5% and ±3%respectively.

3. Results and discussions

In this study, the execution of the heat pipe is studied by differing the parameters, for example, inclined angle and heat inputs. The charging amount of working fluid is 0.060%(φ volume concentration).The inclination angle is varied between 0°and 90°and the heat input is varied from 40 to 200 W. Heat balance equation is used to calculate the heat transferred (Q_ out) by the heat pipe.

$Q_{out} = mC_p(T_{out} - T_{in})$

where m is the mass flow rate of the coolant and cp is the heat capacity of the coolant. Tout and Tin are the temperature of the

Cooling water at the outlet and inlet, respectively.

Heat load was supplied by the resistance heaters with different values of 40 W, 80 W, 120 W, 1600Wand 200 W. Power was measured with the guide of a voltmeter and ammeter as portrayed in the figure. This value could be indicated as:

$Q_{in} = VI$
Where V is voltage and I is current
The thermal resistance of the thermosyphon is calculated as
$R = (T_e - T_c) / Qin$
Where Te and Tc are the normal evaporator and condenser temperatures individually

Fig. 3(a–c) demonstrates the wall temperature profiles of mesh type wick heat pipe with DI water as base liquid at flat, inclined and vertical positions separately, and Fig. 4(d–f) demonstrates the wall temperature profiles of heat pipe with CuO nanofluid as base fluid at flat, inclined and vertical positions separately From the Fig. 4(a–f) it is found that the wall temperature increments as the heat input increments for both DI water and CuO nanofluid heat pipe at all inclined angles. Also it is seen that the evaporator temperatures of the heat pipe are higher than the temperature at the adiabatic and condenser sections. Along the height of the heat pipe, the temperature diminishes for water and CuO nanofluid all conditions at all inclined points. Further it is seen that the evaporator temperature distribution of the heat pipe with CuO nanofluid at horizontal and inclined position (Fig. 3(a) and (b)) is uniform contrasted and mesh type wick heat pipe with DI water as base fluid (Fig. 3(d) and (e)). This variation is due to the change in boiling dynamics at the evaporator portion.

It is clearly seen that the mesh type wick consists of numerous cavities also mesh wick worked efficiently with CuO nanofluid compared with DI water However, the use of CuO nanoparticles leads to the formation of a thin porous coating layer over the mesh wicks. This layer increases the thermal performance by improving the surface wettability and capillary force. Moreover, shows that the CuO nanoparticles coated over the mesh wick are evenly distributed and hence the function of CuO/DI water nanofluid in the mesh wick is more effective. The porous coating layer present in the mesh wick surface with that nanofluid is assessed by counting the number of pores per micrometer range and determining for the entire evaporator. It is found that the total porous coating present in the evaporator of the mesh wick heat pipe with CuO nanofluid are higher than the mesh wick surface with DI water. This will drastically reduce the wall temperature of the mesh wick surface with CuO nanofluid and improve the heat transfer. Further the evaporator performance of the mesh wick TPCT with CuO nanofluid is depends on the porous coating, bubble diameter and thermo physical properties of working fluids.

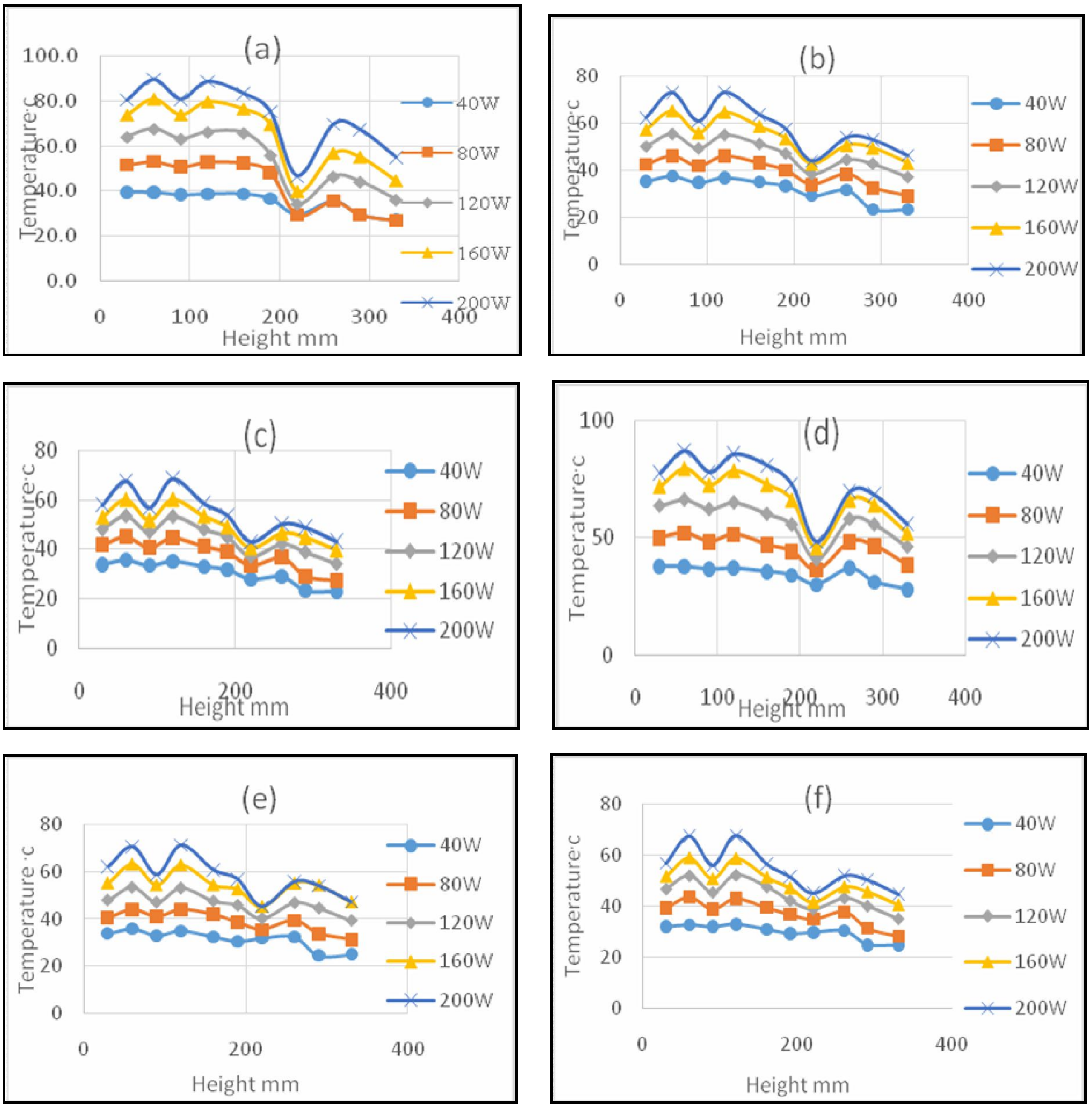


Fig 3. Wall temperature profiles of heat pipe with DI water at (a) horizontal (b) inclined and (c) vertical positions, Heat pipe with CuO nanofluid at (d) horizontal (e) inclined (f) vertical position

Further to concentrate on the heat transfer performance of heat pipe, the heat transfer coefficients of the heat pipe are resolved from Eqs

$h = q/\Delta T$

$q = Q_{in}/dl$

The temperature difference between evaporator and condenser is calculated from below Eqs

$\Delta T = T_e - T_c$

T_e = Average evaporator temperature

T_c = Average condenser temperature

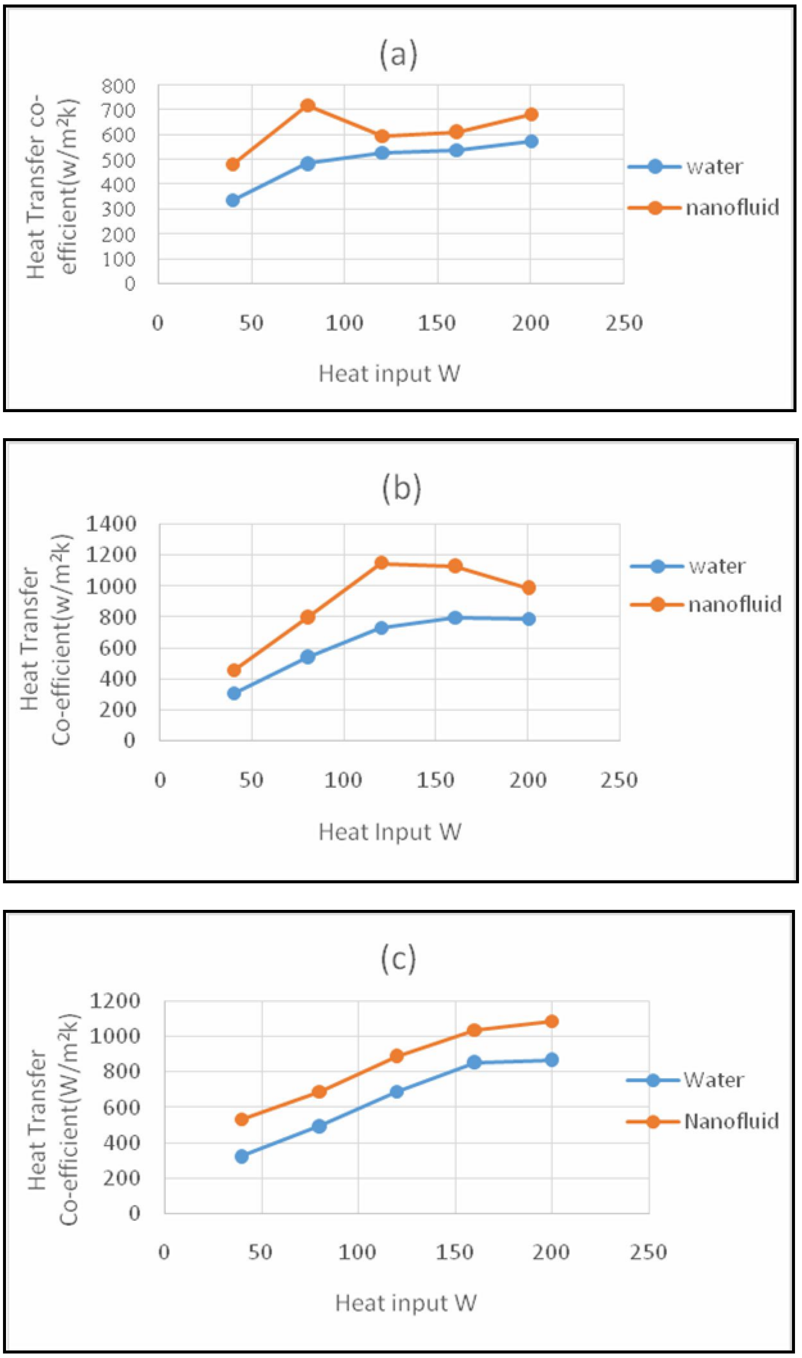


Fig 4.Comparison of Heat transfer co efficient in mesh type wick heat pipe at (a) horizontal (b) inclined (c) vertical

Fig 4 (a-c) shows the heat transfer co efficient of heat pipe (water and Cuo nanofluid) at horizontal, inclined, vertical positions. It is seen that the heat transfer co efficient for CuO nanofluid is higher than that of DI water as base fluid. Heat transfer co efficient is increasing so as to expand heat information (with the exception of inclined position). A greatest heat transfer co efficient upgrade of 35%, 43%, 27% (CuO nanofluid) contrasted and DI water at the position of vertical, inclined, horizontal separately. It is mainly due to higher thermal performance of CuO nanofluid in meshed wick compared with DI water. Combination of meshed wick and CuO nanofluid makes higher porous medium surface compared with DI water. Higher porous medium surface creates higher heat transfer co efficient in nanofluid compared with base fluid.

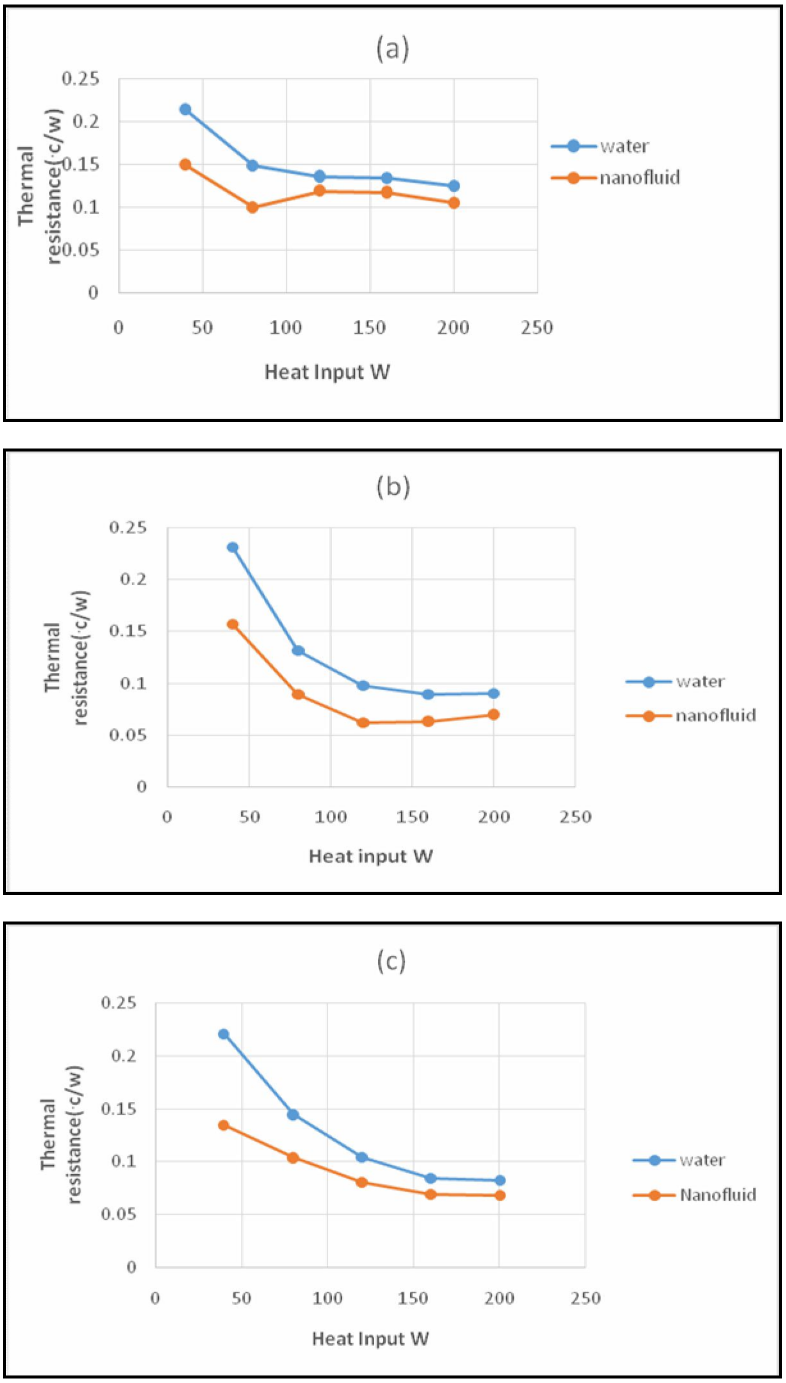


Fig 5. Comparison of Thermal resistance with DI water andCuO nanofluid at (a) horizontal (b) inclined (c) vertical positions

The thermal resistance of heat pipe at various inclination angles for meshed type wick with CuO nanofluid and DI water is shown in fig. It shows that the thermal resistance decreases gradually with increasing heat input at the position of inclined and vertical while compared with DI water. The difference in the thermal resistance between CuO nanofluid and DI water is high at low heat input at the position of horizontal and inclined and it decreasing as the heat input increases. The maximum thermal resistance of 24%, 30%, and 20% are obtained at the position of vertical, inclined, horizontal respectively.

4. Conclusion

In this paper, effect of mesh type wick on the inside wall of heat pipe with DI water and CuOnanofluid has been studied. The mesh type wick is performed at the inside wall of heat pipe. The mesh type wick heat pipe process makes porous structure and enhances heat transfer with CuO nanofluid compared with DI water (base fluid). Due to this heat pipe, wall temperature, heat transfer co efficient is calculated. Also thermal resistance of heat pipe with CuO nanofluid decreases compared to TPCT with DI water (base fluid). It is noticed that heat transfer co efficient enhanced up to 35%, 43%, and 27% for CuO nanofluid obtained at the position of vertical, inclined, horizontal respectively compared to that of DI water. Due to this enhancement in the heat transfer co efficient, thermal resistance of the heat pipe is reduced up to 24%, 30%, and 20% at vertical, inclined, horizontal position respectively.

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