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“Effects of Ceo/H$_2$o Nano Fluid Application on Thermal Performance of Mesh Wick Heat Pipe”

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***Abstract:** In the present investigation, CeO/H_2O nanofluid has been used as a working fluid in the heat pipe. The effects of CeO/H_2O nanofluid application in heat pipe for a wide range of power input (50-150 watts), and inclination angles (0°, 15°, 30°, 45°, 60°,75° & 90° with the horizontal) have been analyzed. Authors noticed 20.5% reduction in thermal resistance and 15.3% enhancement in thermal efficiency of the heat pipe as compared to water. Maximum thermal efficiency (66.5%) of heat pipe obtained at 150 watts and 1.0 vol. % of nanofluid in a horizontal position. Investigation shows that a 30° inclination angle is the most favourable angle for the enhancement in thermal performance of heat pipe.*

***Index Terms:** Heat pipe, Nanofluids, Thermal resistance, Thermal conductivity.*

I. INTRODUCTION

Heat pipes (HPs) are the most effective solution for the effective cooling of electronics devices. Enhanced thermophysical properties of working fluids are responsible for the change in thermal performance of heat pipes (TPHPs). Researchers noticed the nanofluids due to their superior thermophysical properties. Nanofluids (NFs) is the new generation of two phase fluids [1]. Due to superior thermophysical properties NFs draw the attention of researchers. Researchers are using NFs in HPs to enhance their operating limitations and thermal performance also. Chandrasekar *et al.* [2] identified the hidden causes and their effects on thermal conductivity (TC) of NFs. Researchers provided an overview of various numerical studies to figure out the different mechanisms and their effects also. Mursheed *et al.* [3] highlighted that particles type, crystal structure, size, and volume fraction are the main parameters which are responsible for the enhancement of thermal conductivity of NFs.

Mesh wick heat pipes (MWHPs) are the most popular among all categories of HPs. Therefore, researchers used nanofluids in MWHPs (Fig. 1) and tried to find out the optimum results. Researchers used various types of mesh wicks depending upon different working condition. Gupta *et al* [4] examined the effect of different operating parameters like charging ratio of working fluid, orientation and input power on TPHP. Researchers noticed that the enhanced thermal conductivity of working fluid is the main reason for enhancement in TPHP. Kole *et al.* [5] studied the TPHP charged with Cu/water NFs. Authors observed a significant enhancement in TPHP. Thermal resistance (TR) was decreased by 27 %. Gupta *et al* [6] reviewed the heat transfer mechanisms responsible for the change in TPHP using NFs. Enhanced TC, an artificial layer of nanoparticles, the Brownian motion of nanoparticles, and enhanced surface wettability were the main reasons for the change in TPHP. Among all proposed mechanism for enhancement in TPHP, the most acceptable phenomenon is the formation of an artificial layer by the deposition of nanoparticles on the mesh surface of HPs. The investigation revealed that this artificial layer improves the surface wettability and operating limitations of HPs. Kim *et al* [7] studied the effect of graphene oxide (GO)/water nanofluids on TPHP. Researchers noticed a 25% reduction in TR in the evaporator section. Senthil *et al* [8] studied the effects of Al_2O_3/H_2O nanofluid on TPHP. Researchers noticed the significant enhancement in TPHP and suggest the application of NFs in practical applications.

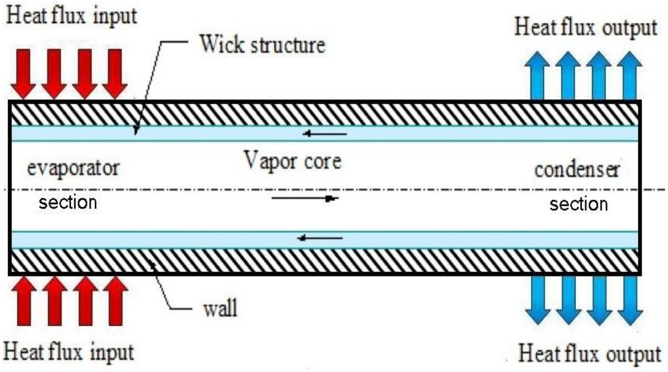

Fig.1. Schematic diagram of a heat pipe

Ramachandran *et al* [9] examined the effects of hybrid nanofluid (Al_2O_3 and CuO with water) on TPHP and noticed the significant effects on TPHP. Researchers suggested that hybrid nanofluids are good alternatives to conventional working fluids. Ghanbarpour *et al* [10] studied the effects of silver nanofluids on TPHP. Researchers noticed the effects of gravity on TPHP. They observed maximum TP at an inclination angle of 60° with the horizontal. Venkatachalapathy *et al* [11] studied the application of CuO/H_2O nanofluid on TPHP and noticed significant enhancement. They noticed 23.83% reduction in TRHP using 1.0 wt. % nanofluid. Gupta *et al* [12] compared the TPHP using NF and nanoparticles coated wick. Researchers find that TP of NF filled and nanoparticles coated wick were higher as compared to water filled HP. Kole and Dey studied the application of Cu/H_2O NF on TPHP. TRHP reduced by 27% using 0.5 wt. % of NF. Authors also noticed that TRHP reduced with the increase in input power.

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Saleh *et al* [13] used ZnO nanoparticles based nanofluid as working fluid in HP. They found that temperature distribution and TR reduced with the increase in concentration and crystalline size. Wang *et al* [14] studied effects of inclination angles on TPHP using CuO/H_2O. The noticed that TPHP was higher for the inclination angle of 45°. Authors noticed that application of NF strengthen the TPHP. Many other researchers [5-16] used different NFs and noticed a change in TPHP. Solomon *et al* [15] examined the effects of copper nanoparticles coated wick on TPHP. Researchers noticed 40% reduction in TR and 40% enhancement in HTC at evaporator section of HP. Similarly, Putra *et al* [16] studied the effects of Al_2O_3/H_2O, Al_2O_3/EG, TiO_2/ H_2O, TiO_2/EG and ZnO/EG on TPHP. Among all, Al_2O_3 /H_2O NF(5% volume) filled HP showed maximum TP. Authors concluded that artificial coating on mesh improved the capillary limit and TPHP.

Tsai *et al* [17] studied the application of gold nanoparticles based NF in HP. Authors demonstrated the effects of NF in CPU based HP and found significant enhancement in TP. Results showed that TP of vertical MWHP varies with size of gold nanoparticles.

Literature shows that limited work has been done on CeO/H_2O NF on MWHPs. Effects of orientation of HP also needs further investigation. CeO shows good stability with water, easily available and lowers cost as compared to other metal oxides. It also has good thermal diffusivity. Therefore, the present experimental study is an attempt to analyze the enhancement in the TPHP charged with CeO/DI water nanofluid as compared to water. Effects of input power and inclination angle on TPHPs are also the objectives of the present study.

1. Experimentation

2.1 *Preparation of nanofluid.*

Application of CeO has been investigated by limited researchers in different applications. In the present study CeO nanoparticles purchased from Alfa-Essar (USA). The weighted nanoparticles were dispersed into water to prepare CeO/Water NF. The mixture was sonicated for 6 hours for good stability. The nanoparticles were in the range of 30-50 nm. Nanofluids of vol. % 0.5, 1.0 & 1.5 have been prepared by two-step method. Sedimentation test has been done to ensure the stability of NF. Samples of NFs were kept for 2 weeks. After 2 weeks, no sedimentation or agglomeration was observed. DLS analysis determines that after slight agglomeration the size of nanoparticles were in the range of 120-140nm.

2.2 Experimental setup

In the present work, the author investigated the TPHP using CeO/H_2O nanofluid. Figure 2 shows the actual view of the experimental setup. Figure 3 shows the schematic view of set up. Heat is supplied through the evaporator section using 500W (circumferential type) electric heater. Control switch of the heater is used to vary the input power. In present work thermostat, water cooling bath system is used to release the heat transfer through the condenser section. K-type thermocouples are mounted on the surface of HP to measure the wall temperatures of all the three sections. Location of all thermocouples has been represented in Fig.4. At evaporator 4 thermocouples (2 at the outer surface and 2 at inner wall surface) ate mounted. Similarly, at adiabatic and condenser section one-one & two-two thermocouples are attached to outer-inner surface respectively. All the thermocouples are attached to a data acquisition system for temperature recording purpose.

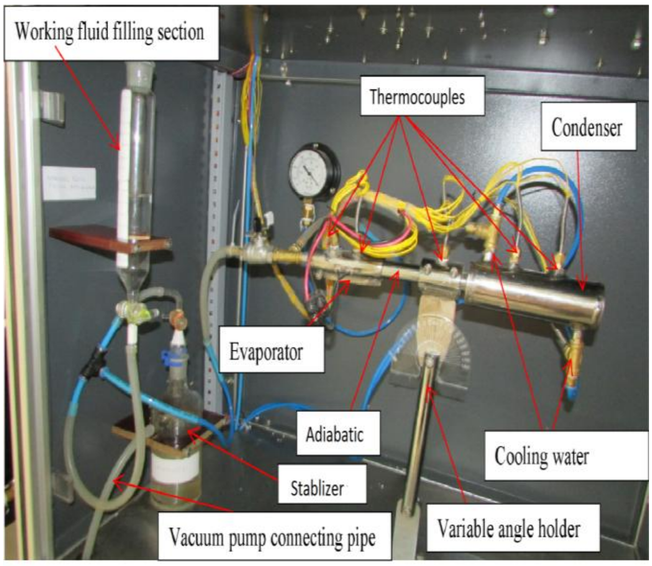

Fig.2: Photographic view of experimental set-up

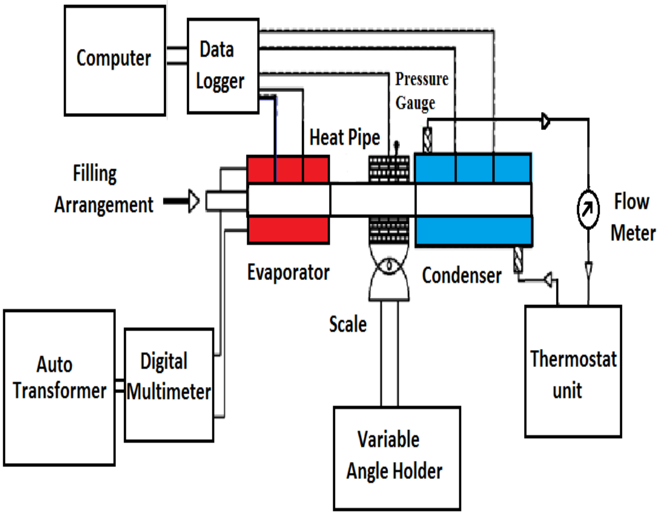

Fig.3: Schematic of the experimental setup

A filling arrangement comprises a vacuum pump, stabilizer, the Vacuum pump is used to maintain the required vacuum pressure inside the HP. A nanofluid charging arrangement has been used to fill different concentration, type of working fluid. The stabilizer is used to maintain a constant vacuum inside the HP. Proper insulation has been provided on the outer surface of the wall. Two thermocouples are mounted on the outer surface of the insulation, to measure the heat loss from the HP. Approximately, 10-15% (of input heat) heat loss has been noticed in present work. At condenser side, the temperature of the inlet and out water was measure by T-type thermocouples. In present work, analysis has been done in a steady state. Therefore, temperatures have been considered after the set attains the steady state.

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The input power supply, concentration of NF, and orientation of HP are the input parameters. Wall temperatures, TR, HTC, and TE are the output parameters.

The uncertainties in measurements of different parameters are shown in table 1.

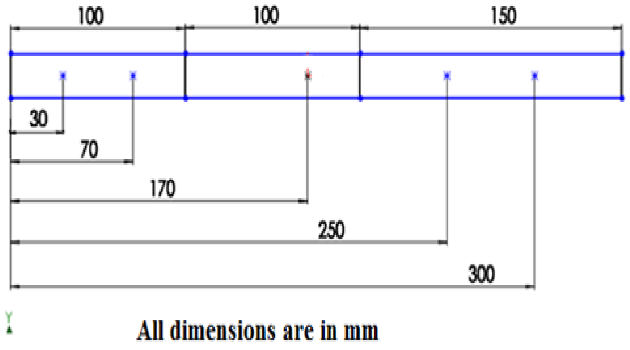


Fig. 4. Location of thermocouples (in mm) on the HP wall surface.

2.2 Uncertainty Analysis

In experimental work, uncertainty analysis is an inevitable step. The uncertainties in the measurement of heat input, heat flux, and thermal resistance are calculated as [14]

$$\frac{\Delta Q}{Q}=\left[\left(\frac{\Delta V}{V}\right)^2+\left(\frac{\Delta I}{I}\right)^2\right]^{1/2} \qquad (1)$$

$$\frac{\Delta q}{q}=\left[\left(\frac{\Delta Q}{Q}\right)^2+\left(\frac{\Delta(\Delta T)}{\Delta T}\right)^2\right]^{1/2} \qquad (2)$$

$$\frac{\Delta R}{R}=\left[\left(\frac{\Delta Q}{Q}\right)^2+\left(\frac{\Delta(\Delta T)}{\Delta T}\right)^2\right]^{1/2} \qquad (3)$$

Table 1: Uncertainties in different measurements

S.N.	**Parameters**	**Uncertainties**
1	Pressure	0.54%
2	Temperature	0.8°C
3	Water flow rate	0.62%
4	Current	0.11%
5	Voltage	0.49%

The uncertainty associated with the heating area was calculated and found to be approximately 1.2%. The uncertainties in the heat loss were 5.2%. The maximum uncertainty in heat supplied, heat flux, and TRHP were 3.1%, 4.8%, and 6.9% respectively.

2.4 Governing Equations of Thermal Performance

The thermal resistance of an HP can be calculated as

$$R= (T_{e\,(avg)}-T_{c\,(avg)})/Q_{in} \qquad (4)$$

$T_{c\,(avg)}$ and $T_{e\,(avg)}$ are the average wall temperatures of the condenser and evaporator section.

The effective thermal conductivity of an HP

$$K_{eff} = L_{eff} / (AxR) \qquad (5)$$

L_{eff} and A are the effective lengths and cross-sectional area of HP.

$$L_{eff} = L_e/2 + L_a + L_{c\,/}\,2 \qquad (6)$$

Where L_c, $L_{a,}$ and L_e are the lengths of the condenser, adiabatic and evaporator section of HP.

$$A = \pi/4\ d^2$$

Heat rejected through condenser section of HP can be calculated as

$$Q=m{*}c_p\,(T_o-T_i) \qquad (7)$$

Where T_i and T_o are the inlet and outlet temperature of cooling water, c_p and m are specific heat and mass flow rate respectively.

2.5 Calibration of experimental set up

In present work, the experimental setup is calibrated by comparing the theoretical and experimental value of heat transport capacity of the HP using D.I. water as working fluid. Figure 5 shows the above comparison. It can be noticed that the theoretical and experimental heat transport capacity of HP are in good agreements.

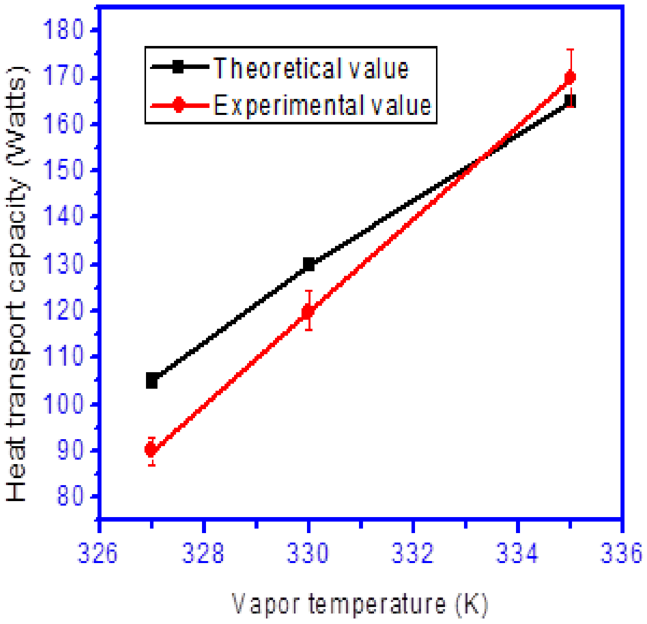
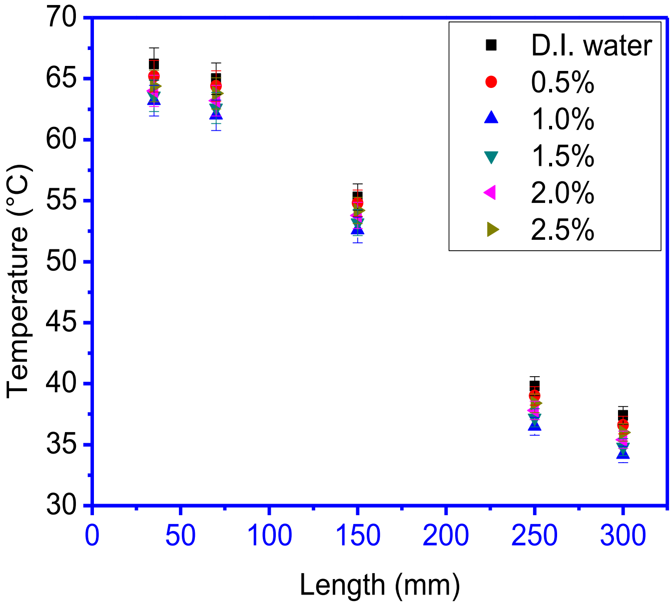


Fig. 5 Heat transport capacity of HP

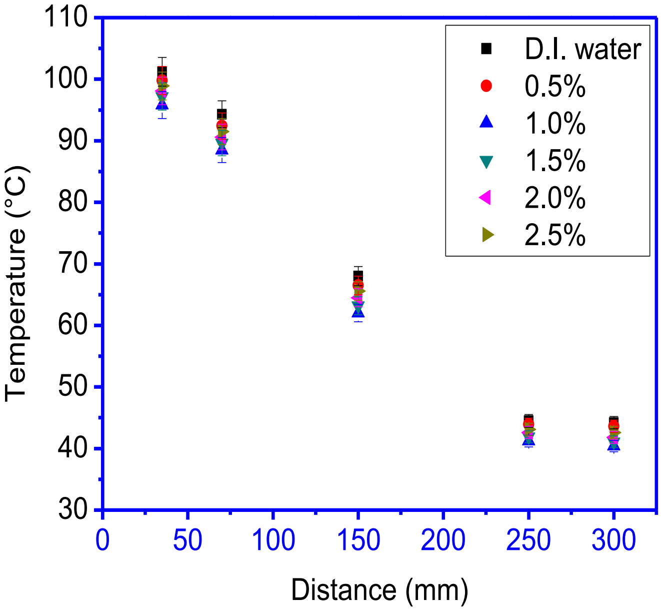
2.6 Result and discussion:

In the present experimental study, wall temperature is the main performance parameter. All the other performance parameter like thermal resistance, convective heat transfer coefficient, and thermal efficiency depends on wall temperature. Reduction in wall temperature is the outcome of enhanced transfer through the HP. Fig. 5(a)-(c) shows the temperature profile along the length of the HP at different heat input (50,100 &150w). Along the length of the HP wall temperature decreases.

2.6.1 Effects of Input Power on Thermal Performance

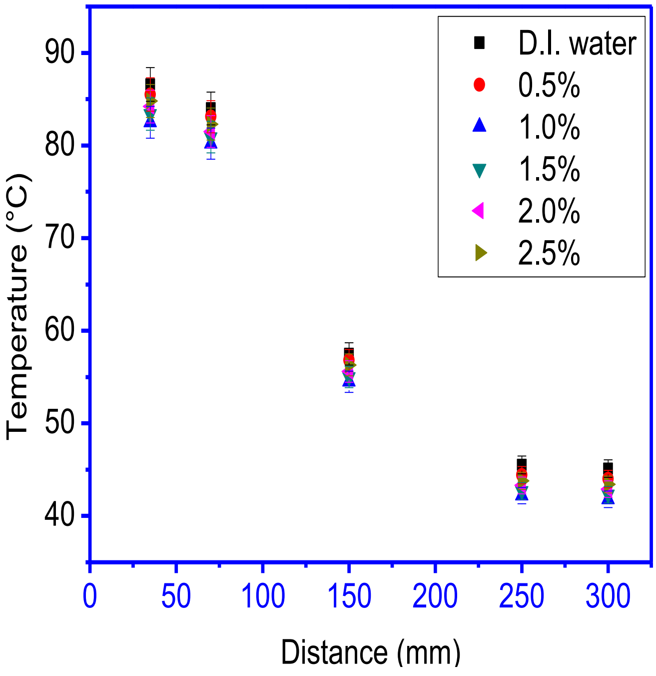


(a)



(C)

Figure 6: Heat pipe wall temperature variations at (a) 50 W (b) 100W and (c) 150W power



(b)

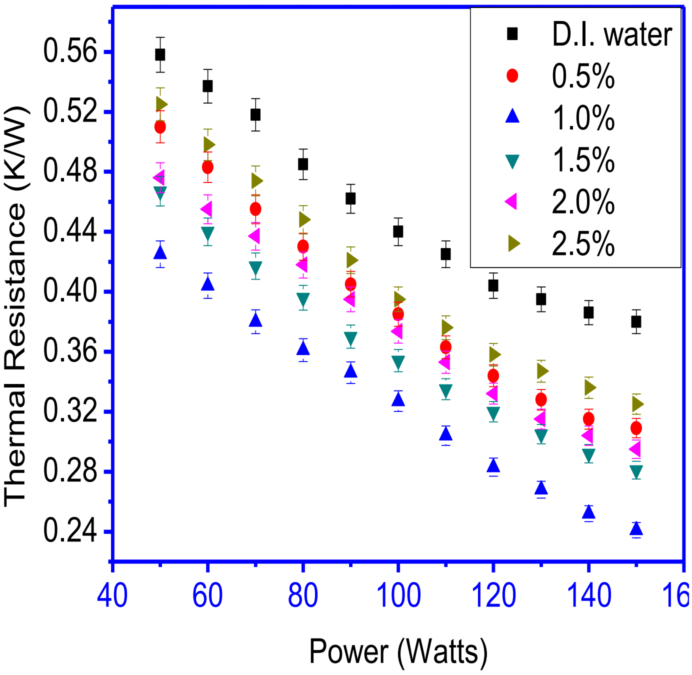


Figure 7: Variation in evaporative thermal resistance with respect to input power

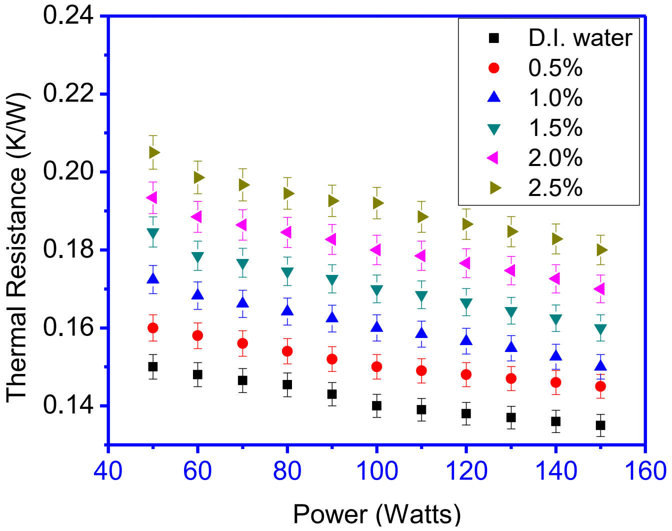


Figure 8: Variation in conductive thermal resistance with respect to input power

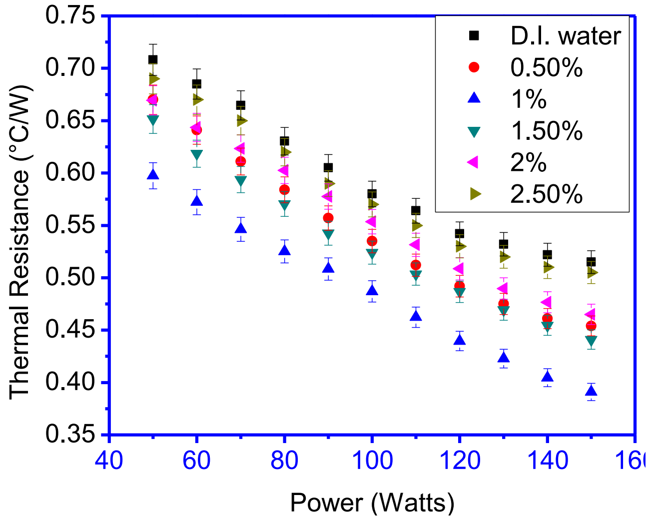


Figure 9: Variation in total thermal resistance of HP with respect to input power

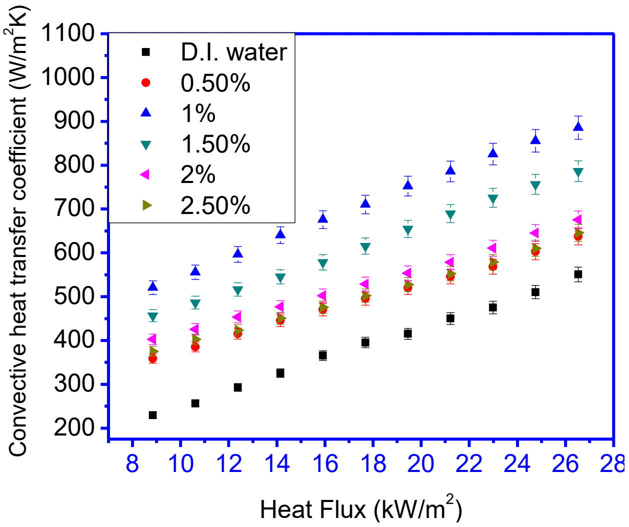


Figure 10: Variation in the convective heat transfer coefficient with respect to power

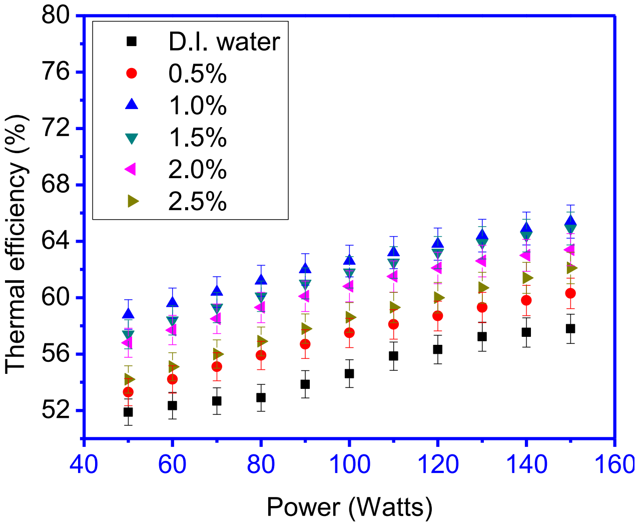
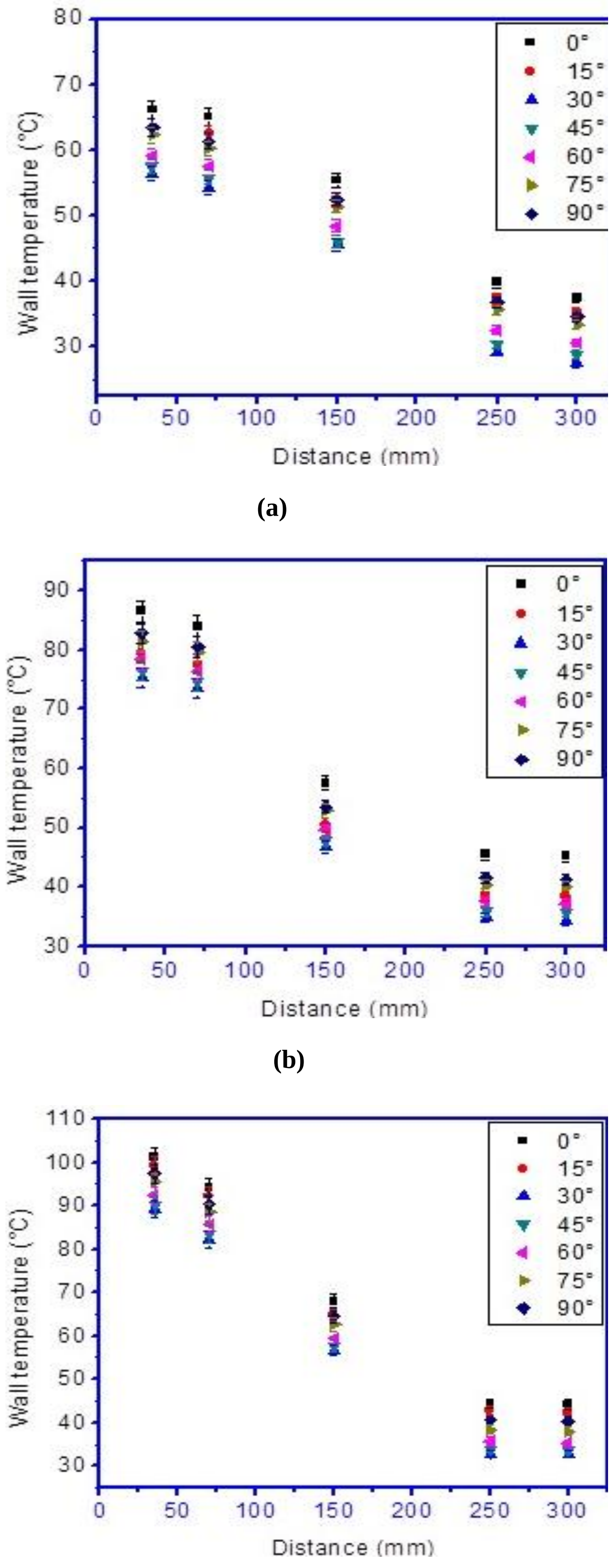


Figure 11: Variation in thermal efficiency with respect to input power

Following conclusions have been drawn by analysing the Fig.6-11.

- CeO/H_2O nanofluid enhanced the TPHP as compared to D I water
- 1.0 vol.% of NF shows the maximum enhancement in TPHP as compared to other concentration.
- The thermal conductivity of NF increases with the increase in concentrations. So up to 1.0% conc. TPHP increases due to the increase in thermal conductivity. As we further increase the concentration, the simultaneous increment in dynamic viscosity and density of NF will also increase. The flow resistance of nanofluid in HP depends upon the density and dynamic viscosity, therefore increment in the concentration of nanofluid upto a certain limit is beneficial for the TPHP but further more increment in concentration causes high flow resistance which finally hampered the performance of HP. So optimum TPHP obtained at a certain point where the positive effect due to the enhanced thermal conductivity of NF is maximum as compared to the negative effect due to the increase in flow resistace.
- Thermal performance increases with respect to an increase in input power. In the present study it increases up to 150watt, beyond 150watt input power due to capillary limitation dry-out condition is observed.

2.6.2 Effects of the inclination angle



(a)

(b)

(c)

Figure 12: Variation in wall temperatures at (a) 50 W (b) 100 W and (c) 150 W

Fig.12 (a), (b) and (c) shows that TPHP is maximum at 30° inclination angle. As the inclination angle increases the downward flow of working fluid will also increase. The enhanced flow of working fluid from the condenser to the evaporator is good for the capillary limitation of the HP. The capillary limitation of HP increases as the inclination angle increases. The dry-out point is also increased which finally increase the heat transport capacity of HP. But as the inclination angle increases the heat interaction time between working fluid vapour and the condenser section is decreases. Due to which the heat release to the condenser section is reduced. Therefore, TPHP is decreased. The maximum TPHP obtained at the inclination angle where the algebraic summation of positive and negative effect is optimum.

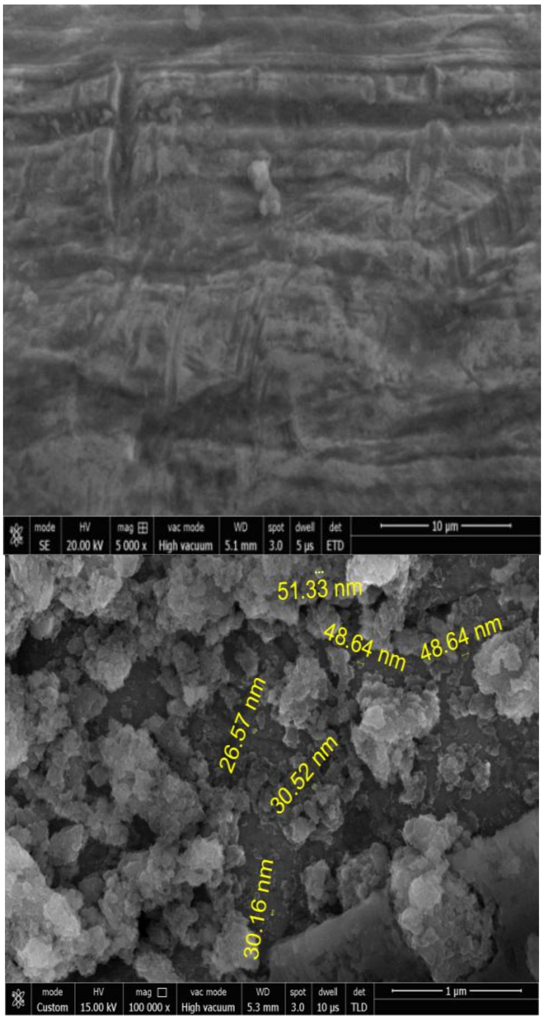


Fig. 13 FESEM images of mesh wick surface, before and after using nanofluid

Fig. 13 shows the wick condition before and after using nanofluid. It can be seen that nanoparticle deposit at the wick surface. Nanoparticle coating plays a major role in the reduction of thermal resistance of HP.

3. Inferences from the present study, existing research gaps, and future scope.

After considering the outcomes of a present experimental study with existing literature, the parameters responsible for changed in TPHPs may be summarized as under-

- Enhanced thermophysical properties of working fluid like thermal conductivity, specific heat, density, viscosity, latent heat, surface tension, stability etc.

- Different operating parameters like concentration/type of working fluid, orientation and heat input affects the TPHP. A most suitable combination of all these will leads the maximum TPHP.
- Effects with respect to working fluid – heat pipe interaction effects such as surface wetting characteristics etc. The parameters responsible for the effectiveness of artificial coating are a method of providing a coating, Critical thickness (i.e. thickness corresponding to maximum heat transfer), porosity, partial detachment rate, surface wettability characteristics etc.
- The effects of working fluids on operational limits like boiling, capillary, viscous, entrainment, and sonic limits.

All the above causes might have an individual as well as the combined effect on TPHP. So Further more study is required to explore the hidden facts to obtain the positive results.

4. Conclusions

In present investigation we observed that CeO/Water nanofluid is very effective working fluid for the heat pipe. Nanofluid filled heat shows higher thermal performance as compared to water filled heat pipe. Heat pipe shows higher thermal performance for higher power. CeO/Water nanofluid (1.0%) and at 30° inclination angle are most favourable operating parameters for nanofluid filled heat pipe. Sedimentation is the major challenge for nanofluid applications. Further research is required to avoid the stability issues of nanofluids.

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