A Experimental and Numerical Approach to Evaluate Thermal characteristics a of Heat Pipe

M K Rawat¹, N K Gupta²

1. Assistant Professor, Department of Mechanical Engineering, GLA Univesity, Mathura, Uttar Pradesh, INDIA-281001
manish.rawat@glau.ac.in
2. Associate Professor, Department of Mechanical Engineering, GLA Univesity, Mathura, Uttar Pradesh, INDIA-281001

Abstract. Nanofluid as working fluid for the improvement of thermal performance, in case of heat pipe, is the newly emerging area of research. Superior thermal characteristics of nanofluids attracted the researchers towards the application of nanofluid in heat pipes. In present study, a 2D analysis is applied to evaluate the thermal performance of heat pipe having CeO₂/H₂O nanofluid. The heat transfer analysis of heat pipe having nanofluid (0.5, 1.0, & 1.5 wt. % concentration) at operating temperature of 60, 80, 100, & 120°C has been done numerically through CFD simulation and results was compared with the experimental results. The results predicted by numerical analysis show that the application CeO₂/H₂O nanofluid diminishes the temperature of surface wall and thermal resistance of heat pipe as compared to that of water. The efficiency as well as effective thermal conductivity of the heat pipe increased with the use of CeO₂/H₂O nanofluid as compared to that of water heat pipe. A good agreement has been observed between experimental and numerical results. The present study concludes that heat pipe using CeO₂/H₂O nanofluid as working fluid has better heat transfer characteristics than the water.

Keywords: Heat Pipe, CeO₂/H₂O Nanofluid, Experimental, specific heat, viscosity, thermal resistance etc.

1. Introduction: In present scenario, the use of heat pipe is the most effective approach for the transfer of heat with limited space and high heat flux. HVAC industries, solar collectors, satellites and spacecrafts, cooling of electronics items like computer, cellphone etc. worldwide use the heat
pipes. A heat pipe are contains a sealed tube of copper or aluminum with a phase change liquid. Different working fluids are used to suit various temperature ranges. Heat pipes can transfer heat with minimal temperature difference between one end and the other. Fig. 1 shows the complete process of transferring heat in a traditional heat pipe filled with a phase change liquid.

1. Heat released by source is absorbed by heat pump in the evaporating section.
2. Phase changing fluid convert into vapour by absorbing heat.
3. Vapour travels toward left end of heat pipe, where it releases heat to the environment; vapor condenses to liquid phase.
4. Liquid again returns to the evaporating section by capillary action of wick material.

Fig. 1. Heat Pipe

Chandrasekar et al.[2] conducted a theoretical investigation by Maxwell model and experimental study to evaluate the viscosity and thermal Conductivity of Al₂O₃/H₂O nanofluid between 0.33–5% concentration 43 nm diameter and they observed that thermal conductivity and viscosity of nanofluids increases as the concentration of nano particles in base fluid increase. Yiamsawasd et al.[3] shows that the thermal conductivity of nanofluid having Al₂O₃ and TiO₂ as nano particle (0–8% by volume ) in between 15–65°C increases with concentration.

Suresh et al.[4] shows that the increase in thermal conductivity is slower than the increase in viscosity of the fluid with concentration of nano particles, in case of Al₂O₃–water nanoFluid. Utomo et al.[5] concluded that the type of nanoparticles, its PH and stabilizer concentration can affect the thermal performance of nanofluids in base fluid. Gupta et al. [6] studied the effect of power input between 50 watts to 150 watts and inclination angle between 0 – 90° from horizontal
direction on a heat pipe having CeO/H2O nanofluid and observed a reduction of 20.5% in thermal resistance and enhancement of 15.3% in thermal efficiency of heat pipe. Cabaleiro et al.[7] observed the decrease in specific heat capacity of the nanofluid particles as the % nanoparticle in the base fluid increase. The reduction in heat capacity up to 12% is observed for both ZrO2 and ZnO while 9% reduction is observed for MgO/EG nanoparticles. Elias et al.[8] evaluate the effects of thermo physical properties of Al2O3 particles on heat transfer between 10 °C and 50 °C with nano particle concentrations (0 to 1% vol.). Specific heat capacity shows a reduction with increase in volume concentrations while other characteristics like viscosity and thermal conductivity and density shows an opposite behavior. With increase in temperature, all the characteristics show the same type of behavior. Gupta et al. [9] summarized the results of various researchers, who have studied the effect of nano materials in the heat transfer application using heat pipe. he also provide the reasons and mechanism of heat transfer responsible for the enhancement in thermal performance of heat pipe. Almost all the researchers’ shows that the enhancement of heat transfer coefficient can be obtained by the addition of optimal concentration of nanoparticles in base fluid. Based on the results provide by the researchers, the presents study focuses on the improvement in thermal performance of heat transfer equipments by varying the concentration in % wt in a temperature range of 80 to 120 ° C. The numerical results of present simulation are also verified with experimental result within acceptable limit.

3. Experimental Method and Nanofluid Preparation

3.1 Nanofluid Preparation

In present study CeO2 nanoparticles with size 55-75 nm were used to prepare CeO2/Water nanofluid. The weighed CeO2 nanoparticles was dispersed into the water to prepare the CeO2/Water nanofluid and then complete mixture is exposed to sonication process continuously for 3 h. Two step methods were used to prepare nanofluid of vol. % 0.5, 1.0 & 1.5. Sedimentation test for 45 days was conducted to verify the stability of nanofluid. No line of separation was observed between nanoparticle and water in 45 days. Dynamic light scattering analysis determines the secondary size of nanoparticles as 140nm. The slight agglomeration of nanoparticles is responsible for the change in the primary and secondary size.
3.2 Experimental Setup
In present experimental study, heat pipe with copper mesh wick has been used. Fig.2 & 3 shows the experimental set up and Thermocouple location on heat pipe respectively. At evaporator, heat is supplied by a heater having facility of power variation. To reduce the heat loss to atmosphere the entire heat pipe is covered with glass wool. To maintain a constant temperature at the condenser section, thermostat cooling bath is used. Thermostat cooling bath maintains 15°C temperature throughout the experimentation work. Ten thermocouples of K-type are attached to measure the external and internal surface temperature of the heat pipe. The Data logger is also attached to all thermocouples to record the temperatures. Inlet and outlet of the cooling water jacket is attached with two thermocouples to measure the temperature.

![Fig. 2. Experimental setup](image)

The adjustable base plate, on which the heat pipe was mounted, is used to study the inclination effect on the thermal performance of heat pipe. Fibre glass wrap was used as insulating material to minimize the Heat losses from all the sections. Fig. 2 shows the experimental test rig. The heat input in the evaporator section is supplied by using six embedded cartridge type heaters. The calculation of heat input was done by measuring the voltage and current using a multimeter. Chilled water was used for the cooling of condenser section and the rate of flow of water was measured with the help of a micro paddle wheel flow meter.
4. Numerical Analysis

Fig. 4 shows the geometry of used heat pipe (front and side view) having total length of 350 mm, internal and external diameters are 20 mm and 22 mm respectively. The computational domain with all boundaries, i.e. Inlet, outlet, wall and wall wick contact surface and central axis as axis symmetric boundary condition is shown in fig. 5. ICEM drafting software was used to draw the geometry and modelling of heat pipe as an axisymmetric concentric tube. ANSYS FLUENT (CFD) software is used to analyze the problem after importing of model.
4.1. Boundary conditions
Between wick and wall surface no slip shear condition is assumed. At evaporator section, the constant heat flux is provided with the help of heaters and constant temperature was maintained at condenser section. Laminar viscous model was selected for simulation. At the centerline, symmetric boundary condition was applied while at outer surface (wall) and wall – wick interface of computational domain, No-slip boundary condition was applied. Wick –wall interface is subjected to a continuous temperature and heat flux. The temperature of vapour - wick interface can be calculated by using Clausius-Clapyron equation.

5. Result and Discussion
The use of CeO2/Water nanofluid in heat pipes causes a significant change in thermal performance. The nanofluid application shows better thermal performance as compared to water. There are many causes/mechanism responsible for the same.

Fig. 5 Variation in temperature difference, thermal resistance, effective thermal conductivity and thermal efficiency with heat input
Fig.5 shows the experimental results for the evaluation of thermal performance of heat pipe with nanofluid as compared to that of with water. Results shows that temperature differences (ΔT) between evaporator mean temperature and condenser mean temperature increases as the input power increases. For the same power, nanofluid shows lower temperature difference as compared to water. Nanofluid with 1.0 vol.% concentration shows minimum temperature difference. Low ΔT at the same power input shows the better thermal performance. Fig. also shows that thermal
resistance of heat pipe reduces as the input power increases. Nanofluid shows lower thermal resistance as compared to water. At the same power input, 1.0 vol. % nanofluid shows minimum thermal resistance. The reason for low thermal resistance is enhanced thermal conductivity, the Brownian motion of nanoparticles and presence of artificial layer. Thermal conductivity and Brownian motion both increases as the temperature increases. Similarly, Fig. also shows the enhancement in effective thermal conductivity and thermal efficiency with respect to temperature. All the thermal characteristics enhanced as the input power increased. Among all nanofluid concentrations, 1.0 vol.% nanofluid shows optimum thermal characteristics. Enhanced thermal conductivity of nanofluid, contributes to enhancement of thermal performance. The existence of an optimum concentration of nanofluid contributes in different ways to the enhancement. Artificial layer (deposited layer) of nanoparticle bombards the bubbles at the interfacial layer. So the number of bubbles, responsible for the thermal resistance decreases, further increases the thermal performance. Nanofluid application enhanced the operating limitation of the heat pipe. The contact angle of solid-liquid interface reduced increases the surface wettability of the heat pipe.

In order to simulate the thermo syphon, heat flux of 10, 15 and 20 kw/m² is supplied as input and at each heat flux, thermal behavior have analyzed. All the graphs shown below, compares the result of CFD simulation (computational fluid dynamics) and experimental results in terms of heat transfer parameters like efficiency, temperature difference, resistance and thermal conductivity.

![Efficiency vs Concentration (Wt%)](image-url)

Fig. 7 Efficiency v/s Concentration (Wt%)
Figure 7 shows the effect of nanoparticles in terms of overall efficiency of heat pipe. Efficiency is increasing with the increment of nanoparticles up to an optimum concentration after that it is decreasing. Results from the experimental as well as numerical simulation show an optimum concentration level for obtaining the maximum efficiency.

Figure 8 shows the comparison between different concentration and the average temperature difference between condenser and evaporator. This increment in temperature difference refers to good heat transfer characteristic.

Fig. 8 Change in Temperature v/s Concentration (Wt%)

Fig. 9 Effective Thermal Conductivity v/s Concentration (Wt%)
Figure 9 shows the variation of effective thermal conductivity with nanoparticles concentration (0-1.5 %). The enhancement in heat transfer capacity of nanofluid is observed up to the 1% Wt concentration, beyond 1% its value again decreases with the addition of nano particles.

Figure 10 shows the variation in total thermal resistance of heat pipe with the nanofluid and water. It is clear that increasing the concentration of nano particles decrease the thermal resistance provides a better thermal performance.

6. Conclusions

The present numerical and experimental analysis shows the effects of the CeO$_2$ / H$_2$O nanofluid on the performance characteristics of heat pipes. The distribution of temperature, thermal resistance, efficiency and effective thermal conductivity are evaluated and compared with heat pipe having water as working fluid. The present analysis shows that the application of the cerium oxide Nano fluids particles as the working fluid in the heat pipe, improves the thermal performance and the volume fraction of nano particles has an impact on the distribution of temperature and heat transfer coefficients. The heat transfer characteristics of any Nano fluids are governed by its type, concentration level of nanofluids, heat pipe geometry and the working conditions. The present analysis shows the optimum concentration value of nano particles to obtain the maximum efficiency. Small differences were observed between numerical predictions and experimental results, the following factor could be responsible for that small difference:
1. The cooling water may affect the temperature of the surface in condenser section.
2. The variation in the porosity due to rolling of the mesh screen wick may affect its effective thermal conductivity.
3. Non-uniform thickness of the wick in the experimental setup may affect the temperature distribution and heat transfer.
4. The excess fluid in evaporator section at lower heat input, which may present in experimental setup, can affect the heat transfer.

Above causes are observed and reported based on numerical and experimental studies. Many more reasons might be possible. So further more detailed studies are required to explore the same.

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