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CFD Validation and Experimental Investigation of Circular Heat Pipe Using Hybrid Nanofluid

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ABSTRACT: An experimentation was carried out to study thermal performance of the heat pipe under different operating conditions. The heat pipe charged with base as distilled water and CuO+ BN hybrid nanoparticles of 40 nm and 70 nm in diameter. The effects of power inputs, heat pipe tilt angle and nanoparticles concentration on the thermal resistance of the heat pipe were investigated. The nanoparticles have a significant effect on the enhancement of thermal performance of heat pipe. Experimental results emphasized that the CuO+BN / H_2O hybrid nanofluids significantly improved the thermal performance of the heat pipe with a volume concentration of 2% for maximal heat transfer enhancement. Compared with distilled water, it is observed that there is a overall decrease of 32 % in thermal resistanceat different heat inputs, inclination angle and concentration than that with the based working fluid at 40% filling ratio.

KEYWORDS: Circular Heat pipe, CuO+BN / H_2O,hybrid nanofluid, Thermal Resistance, Volume fraction, Inclination angle

I. INTRODUCTION

In present energy crisis scenario,Nanofluid two-phase flow and thermal physics have the potential to improve heat transfer and energy efficiency in thermal management systems.

Nanofluids possess remarkably higher thermal conductivity and greater heat transfer properties compared with conventional pure fluids. Nanofluids are found to exhibit a noticeable changes in their thermophysical rheological properties such as specific heat, thermal conductivity, density and viscosity due to the nanoparticle types and concentrations.

Modern Nanotechnology provides new opportunities to process and produce materials with average crystallite sizes below 50nm. Fluids with nanoparticles suspended in them are called nanofluids, a term proposed in 1995 by Choi of the Argonne National Laboratory, U.S.A. (Choi, 1995). Nanofluids can be considered to be the next-generation heat transfer fluids because they offer exciting new possibilities to enhance heat transfer performance compared to pure liquids. They are expected to have superior properties compared to conventional heat transfer fluids, as well as fluids containing micro-sized metallic particles. The much larger relative surface area of nanoparticles, compared to those of conventional particles, should not only significantly improve heat transfer capabilities, but also should increase the stability of the suspensions. Some of the common oxide nanoparticles being used in heat transfer research are Zinc Oxide (ZnO), Copper Oxide (CuO), Aluminum Oxide (Al2O3), and Titanium Oxide (TiO2) while some of the metal nanoparticles are Gold (Au), Silver (Ag), and Copper(Cu).Nanofluids can improve abrasion-related properties as compared to the conventional solid/fluid mixtures. Necessary studies need to be carried out before wide application can be found for nanofluids.

II. LITERATURE REVIEW

M.G.Mousa et al [1] carried out an experimental study on an effect of nanofluid in Circular Heat Pipe. The nanofluid consisted of Al2O3 nanoparticles with a diameter of 100 nm. The experimental data of the nanofluids were compared with those of DI water including the wall temperatures and the total heat resistances of the heat pipe. Experimental results showed that if concentration of the nanofluid increasing, then the thermal resistance of heatpipe decreased. Shang et al [2] investigated the heat transfer characteristics of a closed loop OHP with Cu–water nanofluids as the working fluid different filling ratios. The results were compared with those of the same heat pipe with distilled water as the working fluid. The experimental results confirmed that the use of Cu–water nanofluids in the heat pipe could enhance the maximum heat removal capacity by 83%. It was confirmed that directly adding nanoparticles into distilled water without any stabilizing agents had greater heat transfer enhancement compared to the case where a stabilizing agent was added to the distilled water. S. Kang et al [3] carried out an experimental study of nanofluid is employed as the working medium for a conventional 211 lm wide. 217 lm deep grooved circular heat pipe. The nanofluid used in this study is an aqueous solution of 35 nm diameter silver nanoparticles. The experiment was performed to measure the temperature distribution and to compare the heat pipe thermal resistance using nanofluid and DI-water. The tested nanoparticle concentrations ranged from 1 mg/l to 100 mg/l.The

condenser section of the heat pipe was attached to a heat sink that was cooled by water supplied from a constanttemperature bath maintained at 400C. At a same charge volume, the measured nanofluid filled heat pipe temperature distribution demonstrated that the thermal resistance decreased 10–80% compared to DI-water at an input power of 30–60 W. The measured results also show that thermal resistances of the heat pipe decrease as the silver nanoparticle size and concentration increase Wei et al [4] used a cylindrical micro-grooved heat pipe with the inner diameter and the length of 6 mm and 200 mm respectively .The width and the depth of the rectangular groove were 211 lm and 217 lm, respectively. The working fluid consisted of silver nanoparticles with an average particle size of 10 nm and pure water. They mainly measured the total heat resistance of the heat pipe filled with pure water and nanofluids. The total heat resistance of the heat pipe using nanofluids could decrease by 28%–44% compared with that of the heat pipe using water. Tsai et al [5] performed an experiment concerning a cylindrical mesh wick heat pipe. The working fluid was an aqueous solution of various-sized gold nanoparticles. The inner diameter and the length of the test copper tube were 6 mm and 170 mm, respectively. A 200 mesh screen was distributed on the inner wall. The number of mesh layers was unknown. The experimental results showed that the total heat resistance of the heat pipe reduced 20%–37% due to the addition of nanoparticles. Result shows the total resistance of the heat pipe for nanofluids of various particle sizes. Lin et al [6] investigated experimentally the thermal performance of a closed loop oscillating heat pipe using nanofluids. They applied water-based silver nanofluids at different volume fractions (100 ppm and 450 ppm) and various filling ratios (20%, 40%, 60%, and 80%). The silver nanoparticle had a diameter of 20 nm. Results showed that the thermal performance of the oscillating heat pipe using nanofluids was better than that using water. The best filling ratio was reported to be 60%. Chen et al [7] experimentally and theoretically investigated the heat transfer performance of flat plate oscillating heat pipes, which were created by machining grooves on both sides of a copper plate. Acetone, water, diamond–acetone, gold–water, and diamond–water nanofluids were tested as working fluids. The thermal resistance was further decreased when the nanofluids was used as the working fluid. It was observed that high-volume fraction diamond–water nanofluids was not stable but settled with time and reduces thermal performance.

III. DESCRIPTION OF THE EXPERIMENT

3.1- Objectives

This work is undertaken to study the heat transfer enhancement of a circular heat pipe using CuO-BN /water nano fluid. The experimentation work is done using a circular heat pipe with the following objectives.

- Effect of different concentration of (CuO-BN/H_2O) hybrid nanofluid /water on thermal resistance of Heat Pipe.
- Effect of inclination angle on thermal resistance of heat pipe.
- Effect of heat input on thermal resistance rate of heat pipe.

A schematic view of the experimental system is shown in Fig.1. The length, outer diameter and wall thickness of the heat pipe were 600 mm, 25.4 mm and 0.5 mm, respectively.The evaporator section, adiabatic section and condenser section of the heat pipe were 150 mm, 300 mm and 150 mm long, respectively.The evaporator section was

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heated by an electrical heater surrounding at its circumference. The condenser section was cooled by cooling water circulating in a constant-temperature thermal bath.

3.3 Preparation and properties of nanofluid

The hybrid nanoparticles used in these experiments were copper oxide and Boron Nitride particles of 40 nm and 70 nm in size. The base working fluid was distilled water. Hybrid nanofluid was prepared using a two step method. CuO +BN nanoparticles were prepared first.The hybrid nanoparticles were then added to pure water.No surfactant is used in the CuO+BN hybrid nanofluid suspension. The mixture was prepared using an ultrasonic homogenizer. Nano-fluid volume concentration of 1% and 2 % is used in this study. An experimental system is setup to measure the thermal resistance of circular heat pipe. The inner diameter and length of the heat pipe used in these experiments were 22 mm and 450 mm, respectively.

3.5 Procedure

- Heating controlled by anF electric heated wire wound in the evaporator wall. The wire is connected to a variator.
- No heating or Dcooling occurs in the adiabatic section.
- For cooling, a Fwater jacket with tap water surrounds the condenser.
- The water flow is measured Fwith a Measuring jar and stop watch.
- Temperatures Jare measured at several positions at the outer wall and at the coolant inlet with K-typeH thermocouples.
- The thermocouples Oare read with a digital thermocouple thermometer.
- The experiments are conducted using three identical heat pipes which are manufactured as per mentioned dimensions. One of the heat pipes is filled with distilled water, second one with 1% aqueous solution of nano fluid (CuO), third one with aqueous solution of 2% hybrid nano fluid.

Experimental procedure is repeated for different heat inputs (25, 50, 75 and 100 W) and different inclinations of pipe (0°, 45° and 90°) to the horizontal position and observations are recorded. The output heat transfer rate from the condenser is computed by applying an energy balance to the condenser flow.

3.6 Result and discussion:

The overall thermal resistance of circular heat pipe is calculate by equation-

$$R_{th} = \frac{T_e - T_c}{Q}$$

Where T_e and T_c are the average wall temperatures of evaporator and condenser section and can be determined by following equations-

$$T_e = \frac{1}{n}\sum_{i=0}^{n} T_i$$

$$T_c = \frac{1}{n}\sum_{i=0}^{n} T_i$$

Optimum results are observed for 2% volume fraction of hybrid nanofluid at an angle of 45° with 100 W heat input.so graphs are shown at optimum conditions only.

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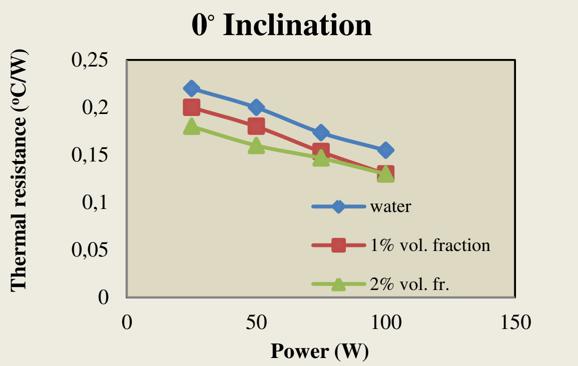
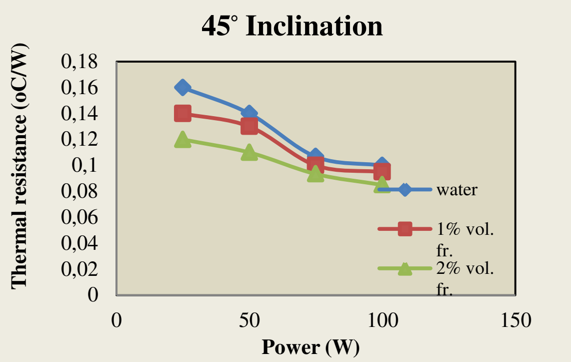
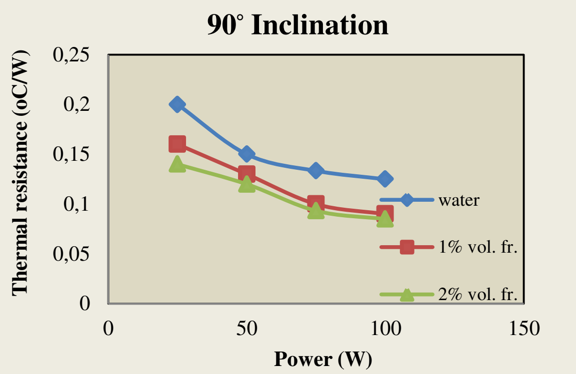


Graph 3.1. Graph of thermal resistance vs. power input for 0^0inclination for various concentrations of nanofluid w.r.t. water



Graph. 3.2:-Graph of thermal resistance vs. power input for 45^0 inclination for various concentrations of nanofluid w.r.t. water



Graph 3.3.: Graph of thermal resistance vs. power input for 90^0 inclinations for various concentrations of nanofluid w.r.t. water

As the concentration of nanofluid and heat input goes on increasing, the thermal resistance of heat pipe goes on decreasing. Graphs.3.1 to 3.3 represent thermal resistance vs. power input for heat pipes charged with working fluid as water ,1%, 2% volume fraction of CuO/BN H_2O hybrid nanofluid for various inclination angles . It is clear that thermal resistance of heat pipes decreases with increasing volume concentration of hybrid nanofluid, angle of inclination and heat input compared with water as working fluid of heat pipe.

At 0^0 inclination angle and 100 watt power input the thermal resistance of heat pipe found experimentally is 0.155^0C/W with water as working fluid of heat pipe. For the same above mention input thermal resistance of heat pipe charged with 1% and 2% hybrid nanofluid found experimentally are 0.13 and 0.13 ^{0}C/W respectively. Thus percentage decreased in thermal resistance observed is 15.38 % With water as working fluid of heat pipe and with increasing inclination angle from 0 to 90^0 thermal resistance decreased by 19.35 % , whereas with 1% and 2% volume fraction of hybrid nanofluid it decreased by 30.76% and 34.61 % respectively With water as working fluid of heat pipe and increasing input power from 25 watt to 100 watt for 0^0 inclination angle thermal resistance decreased by 29.54% , whereas with 1% and 2% volume fraction of hybrid nanofluid it decreased by 35 % and 37.12% respectively **.**With water as working fluid of heat pipe and increasing input power from 25 watt to 100 watt for 90^0 inclination angle thermal resistance decreased by 37.5% , whereas with 1% and 2% volume fraction of hybrid nanofluid it decreased by 43.75 % and 46.28 % respectively . The reason for reducing the thermal resistance of heat pipe can be explain as follow reduction in thermal resistance of heat pipe is caused by not only due thermo- physical properties of nanofluids but also due to formation of thin porous coating layer produced by the nanoparticels on evaporative region .The coating layer formed by nanoparticle improves surface wet ability by reducing the contact angle and increasing surface roughness ,which in turn increases critical heat flux and it significantly reduces thermal resistance of the heat pipe

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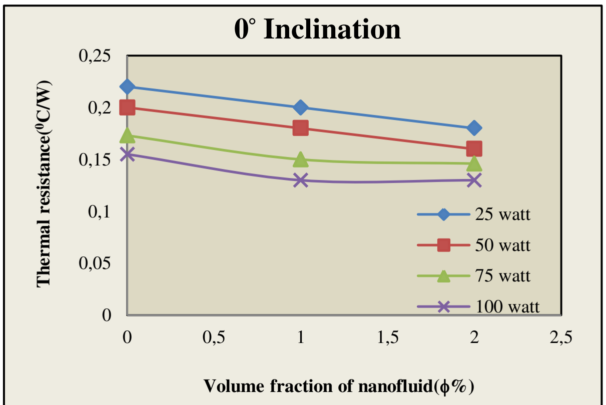
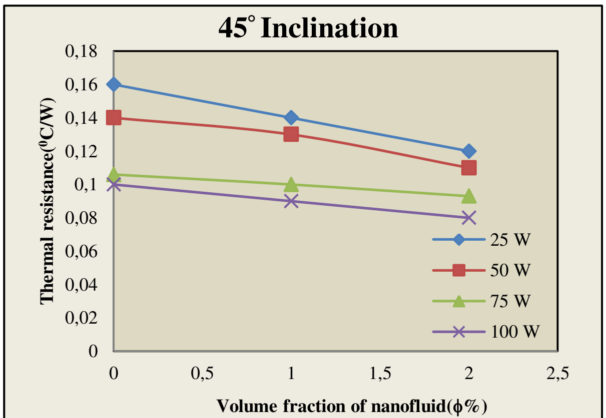
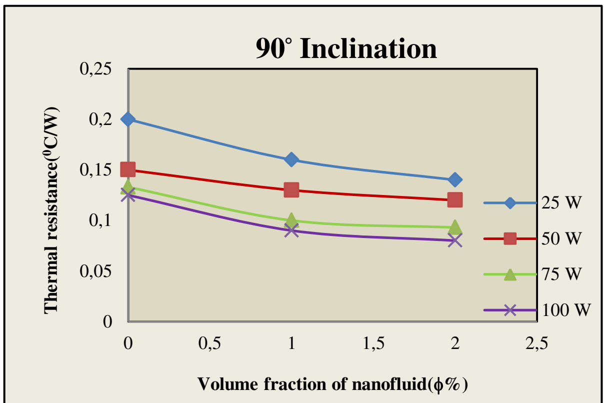
using hybrid nanofluid.



Graph 3.4.: Graph of volume fraction vs. thermal resistance for 0^0 inclination for various power input



Graph 3.5: Graph of volume fraction vs. thermal resistance for 45^0 inclination for various power input



Graph 3.6.: Graph of volume fraction vs. thermal resistance for 90^0 inclination for various power input

Figure 3.4 to 3.6shows the influence of the hybrid nano particle volume fraction on the thermal resistance of heat pipe.The thermal resistance of the hybride nanofluid heat pipe monotonically decreases with increase in the volume fraction. The increase of volume fraction couse the increase of bothe the thermal conductivity and viscocity of the bybrid nonfluid The thermal conductivity become conciderably larger compare to viscocity of the bybrid nonfluid as the volume friction increases This lead to improvement of the evaporation heat transper in liquid film and the thermal resistance of the bybrid nonfuid heat pipe is reduse with increasing volume friction. When small amount of nanoparticle is added into the base fluid a thin porous costing layer on the inner surface with high heat transoer performance is creat This leads to readuce in the thermal resistance of bybrid nonfuid heat pipe.

IV. CFD VALIDATION

This model consists of two phases i.e. vapors liquid with addition of that nano particle. Multiphase model issued as Eulerian model with density discrete phase model. One section defined as water liquid and other section is defined as water vapors phase one is defined as water liquid and phase two is defined as water vapor. Energy equation is used for temperature distribution. Experimentaly it is observed that optimum results are at 45° and 100 W heat input for 2% concentration of nanofluid.CFD validation is done for this particular optimum condition.

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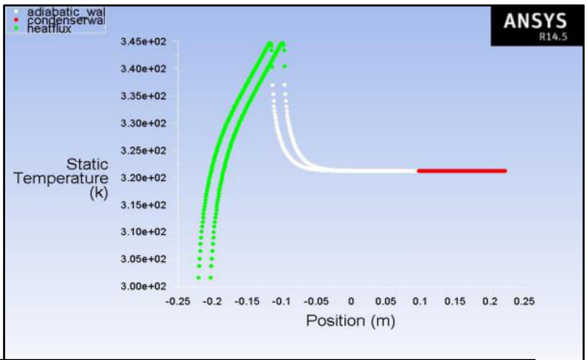

Fig.4.1.Temperature variation for 100 watt inclined heat pipe (45^0)

Figure shows variation of temperature along length direction. Addition of nanofluid with varying percentage increases temperature along length direction because of increase in thermal conductivity of nano fluid. Viscous effect results are also comparable with and without result.The CFD validated results for temperature distribution over heat pipe surface corresponds nearly with experimental results.

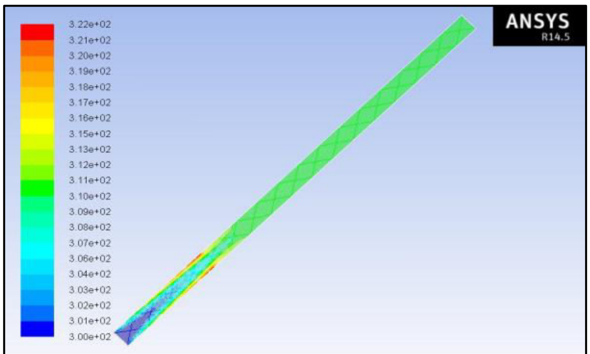

Fig.4.2 Temperature contours for 100 watt inclined heat pipe (45°)

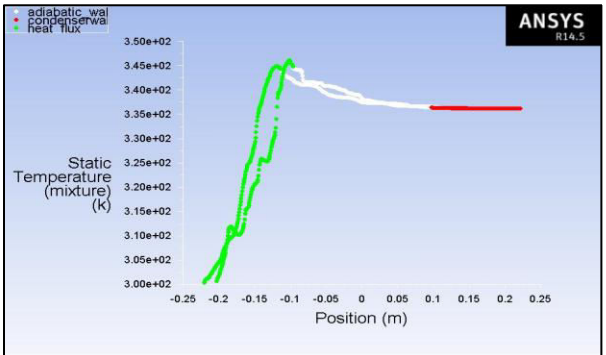

Fig.4.3Temperature contours for 100 watt inclined heat pipe at 45^0

V. CONCLUSION

This anslysis discusses the thermal enhancement of circular heat pipe performance using CuO-BN/Water hybrid nanofluid as working fluid.For that purpose the effect of different concentration of hybrid nanofluid, inclination angle, heat input on thermal resistance of circular heat pipe is studied. From the experimentation the following conclusions can be drawn

- Thermal resistance of circular heat pipe decreases with increase in volume concentration of hybrid nanofluid, increase in heat input and increase in inclination angle compared with distilled water as working fluid.
- With increase in the volume concentration of hybrid nanofluid the thermal resistance of circular heat pipe for 2% volume concentration of hybrid nanofluid as working fluid reduces by an amount of **32.00%** compared with distilled water as working fluid.
- With increase in the inclination angle of circular heat pipe the thermal resistance reduces. for 2% volume concentration and variation in inclination angle from 0^0 to $90^0$for hybrid nanofluid as working fluid thermal resistance reduces by an amount of **33.62 %** compared with distilled water as working fluid.
- With increase in the heat input of hybrid nanofluid the thermal resistance of circular heat pipe reduces. For variation in heat input from 25W to 100W and inclination angle of $0^0$for 2% volume concentration of hybrid nanofluid as working fluid it reduces by an amount of **39.28 %** compared with distilled water as working fluid.

From the above experimentation it is concluded that the circular heat pipe using hybrid nanofluid as working fluid can give the promising results compared with water as working fluid.

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