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THERMAL PERFORMANCE OF SCREEN MESH WICK CYLINDRICAL HEAT PIPE USING CuO (Copper Oxide) NANOFLUID

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ABSTRACT

This study presents the effect of using Copper Oxide (CuO) Nanofluid (pure water mixed with CuO nanoparticle with 40nm diameter) on the thermal efficiency enhancement of a heat pipe on the different operating state was investigated and also thermal performance of inclined screen mesh heat pipe in cooling applications. The heat pipe was made of a straight copper tube with an outer diameter of 8mm and length 300mm and stainless steel of 1mm wick thickness for heat pipe. Four cylindrical copper heat pipes containing one layer of screen mesh were fabricated and tested with distilled water and water based Copper oxide nanofluids with mass concentrations of 1%, 2%, and 3% as working fluids. The experiments were performed at four inclination angles of 0°, 30°, 60° and 90°. The main focus of this study is to investigate inclined heat pipe performance with CuO nanofluid. Experimental results indicate that the thermal performance of heat pipes was improved with nanofluids compared to distilled water and thermal resistance of the heat pipes decreased with the increase of nanoparticle concentration. Moreover, the thermal performance of the heat pipes at inclination angle of 90° is found to be higher than other tested inclined angles. The thermal efficiency of heat pipe charged with Nanofluid is compared with pure distillation water.

Key words: Heat pipe, Nanofluid, Thermal performance.

I.INTRODUCTION

Heat pipe, as a two-phase heat transfer device, has been used for cooling application of high power electronic devises. The reason which makes it as a popular heat transfer device is its flexibility and high effective thermal performance in comparison with common thermal conductors such as metal rods and fins. The thermal performance of a heat pipe is influenced by many parameters such as wick type, porosity and permeability, working fluid, filling ratio and operation conditions such as orientation and heat input. During recent years, nanofluids (NFs) have been suggested as working fluids to enhance heat pipes thermal performance. Various types of NFs with different concentrations, particle sizes and shapes have been used and interesting results on thermal performance enhancement are achieved Liu and Zhu studied effects of aqueous CuO NFs on thermal performance of a horizontal mesh heat pipe experimentally. They investigated the effects of nanoparticles mass concentration and operating pressure on thermal performance of the heat pipe. They found that the average evaporator wall temperatures of the heat pipe using NFs decreased compared with those of the heat pipe using deionized water which resulted in 60% smaller thermal resistance of the heat pipe at 1wt% CuO NF. Wang et al. investigated experimentally thermal performance of a cylindrical miniature grooved heat pipe using aqueous CuO NF. It was found that the evaporation heattransfer coefficient and maximum heat flux were increased by one time and 35%, respectively when NF was used as a working fluid instead of water in the heat pipe. Hung et al.performed experiments to investigate the effect of Al2O3/water nanofluid on heat pipe thermal performance. They studied the effects of nanofluids concentrations, tilt angle, heat pipe length and filling ratio on overall thermal conductivity of the heat pipe. They found that in all cases the optimal thermal performance for NF is much better than that of heat pipes with distilled water. Putra et al. investigated experimentally the thermal performance of screen mesh wick heat pipe with various NF. The experiments were carried out to determine the influence of concentrations at different types of nanofluids. Al2O3/water, Al2O3/ethylene glycol, TiO2/water, TiO2/ethylene glycol and ZnO/ethylene glycol with different concentrations were charged in the screen mesh wick heat pipe. They found that the heat pipe with NF has higher heat transfer coefficient than with the base liquid. Moreover, their results showed that a thin Nano porous layer coated the surfaces of the wick after using NF caused this enhancement due to promote good capillary structure.

II. RELATED WORK

Heat pipe consists of three main sections: an evaporator section, an adiabatic section, and a condenser section. When heat input is provided at the evaporator section it vaporizes the working fluid, which is in equilibrium with its own vapour. This creates a pressure difference between evaporator section and condenser section, which drives the vapour through the adiabatic section. At the condenser section, heat is removed by condensation i.e. by providing cooling water through outlet surface or by providing fins and it is ultimately dissipated through an external heat sink. The capillary effect of the wick structure will force the flow of the liquid from condenser to evaporator section. The adiabatic section is insulated in order to neglect the heat losses. The Fig.1 shown below explains the principle of heat pipe.

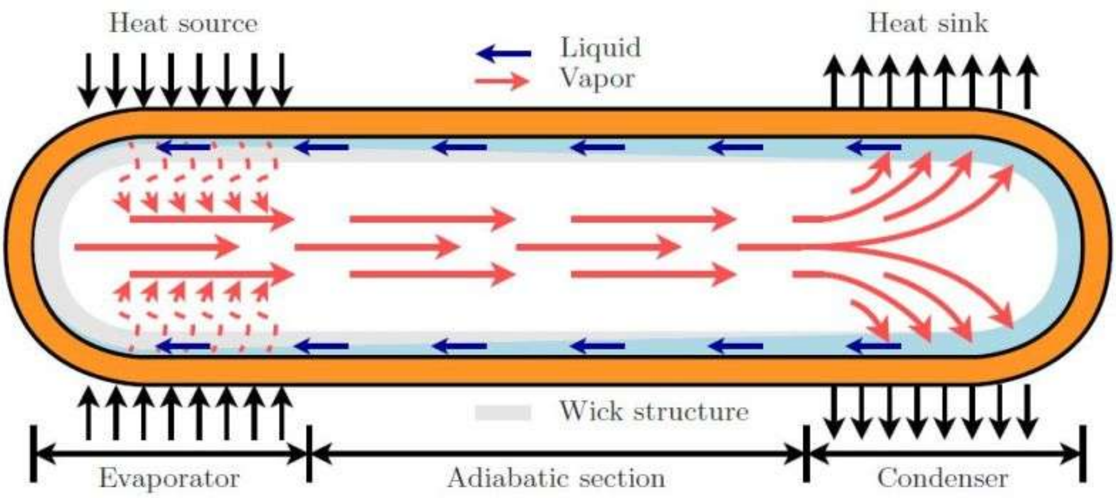

Fig.1: Heat pipe principle

Heat pipe operates on a closed two-phase cycle and utilizes the latent heat of vaporization to transfer heat with a small temperature gradient. Heat pipe consists of three main parts, which are the pipe, wick (screen mesh) structure and working fluid. The pipe is normally constructed from metal. Wick structure is constructed from woven fiber glass, sintered metal powders, screen, wire meshes, or grooves. Working fluid used varies differently for different working fluids. In order to fabricate a working heat pipes, all three parts are given important consideration to the material type are showed in Fig.2

Fig.2: Gravity free Heat pipe types

III. CUO (COPPER OXIDE) NANOFLUID

Nanoparticles research is gaining increasing interest due to their unique properties, such as increased electrical conductivity, toughness and ductility, increased hardness and strength of metals and alloys, luminescent efficiency of semiconductors, formability of ceramics.The properties and applications of copper oxide nanoparticles are Copper is a Block D, Period 4 element, while oxygen is a Block P, Period 2 element.Copper oxide nanoparticles appear as a brownish-black powder. They can be reduced to metallic copper when exposed to hydrogen or carbon monoxide under high temperature.

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Fig.3: Copper oxide (CuO) Nanofluid

3.1Chemical Properties:

The chemical properties of copper oxide nanoparticles are outlined in the following table.

Chemical Data	
Chemical symbol	CuO
CAS No.	1317-38-0
Group	Copper 11 Oxygen 16
Electronic configuration	Copper [Ar] $3d^{10}$ $4s^1$ Oxygen [He] $2s^2$ $2p^4$
Chemical Composition	
Element	**Content (%)**
Copper	79.87
Oxygen	20.10

3.2 Physical Properties:

The physical properties of copper oxide nanoparticles are given in the following table.

Properties	Metric	Imperial
Density	6.31 g/cm^3	0.227 lb/in^3
Molar mass	79.55 g/mol	-

3.3Thermal Properties:

The thermal properties of copper oxide nanoparticles are provided in the table below.

Properties	Metric	Imperial
Melting point	1201°C	2194°F
Boiling point	2000°C	3632°F

3.4Manufacturing process:

Copper oxide nanoparticles can be synthesized using the aqueous precipitation method. In this method, copper acetate is used as a precursor and sodium hydroxide as a stabilizing agent.Single phase monoclinic structure of the copper oxide nanoparticles is revealed using X-ray diffraction. The rectangular morphology of the copper oxide nanoparticles is revealed using the scanning electron microscopy.

3.5 Applications:

The key applications of copper oxide nanoparticles are as follows:

- Soluble in water & dilute acids, NH4Cl, (NH4) 2CO3, potassium cyanide solution.

- Nano copper oxide is a widely used material.
- It has been applied to the catalyst, superconducting materials, thermoelectric materials, sensing materials, glass, ceramics and other fields.
- In addition, the Nano-copper oxide can be used as rocket propellant combustion catalyst. It not only can significantly improve the homogeneous propellant burning rate, lower pressure index, but also can better perform as the catalyst for the AP composite propellant. More use such as: Ceramic resistors, Gas sensors, Magnetic storage media, Near-infrared tilters, Photoconductive and photo thermal applications, Semiconductors, Solar energy transformation, Catalysts, High-tech superconductors.
- Die casting and injection moulding
- Ventilation heat recovery and other energy conserving uses.
- Nuclear power conversion
- Aerospace applications, military devices, temperature control system, and personal computers
- Medical field, Cooking and space craft's etc.

- In production tools, human body temperature control.

IV. EXPERIMENTAL STUDIES

4.1 Experimental setup:

A schematic diagram of the experimental apparatus is in the test loop consists of a test section, cool water loop and data acquisition system. The close-loop of cold water consists of a 0.125 m3 storage tank. The cold water is controlled by a temperature controller and is pumped out of the storage tank. The cooling water is set at the temperature of 20±0.5 °C with a flow meter (accuracy: 0.2%, uncertainty: 0.017 L/min) monitoring the fixed flowing volume. The temperature of the experimental environment is controlled at 25±1 °C, and the heat pipe of the study is a straight copper tube with an outer diameter and length of 8mm and 300 mm respectively. The heat pipe contained a 1 mm wick-thickness of stainless steel heat pipe. The condenser section of the flat heat pipe was inserted vertically in to the cooling chamber. The coolant circulated through the cooling chamber, where heat was removed from the condenser section by forced convection and then to a constant temperature bath.

The test section consists of three sections evaporator, adiabatic and condenser section. The evaporator section of the heat pipe was heated by an electrical heater surrounding at its circumference and the power supply to the heater is given by the variac. The amount of power supplied to the heater is calculated by measuring the voltage and ammeter readings as shown in Figure. The heat pipe is charged with pure water 1%, 2%, and 3% of working fluid. A layer of stainless steel wick is used in the inner wall of the heat pipe to provide capillary pumping force of the working fluid and a coarse wick to support and maintain the structural integrity of the vapour space. An acrylic pipe is used in the condenser section to provide the circulation of cooling water which is located at the end of the heat pipe to remove the heat of the working fluid. Araldite is used to close the sides of acrylic pipe and left for a day to harden it. The heat pipe has the ability to transfer the heat through the internal structure. As a result, a sudden rise in wall temperature occurs which could damage the heat pipe if the heat is not released at the condenser properly. Therefore the cooling water is circulated through the entire process. The flow rate of water is measured and kept constant throughout the experiment.

The inlet and outlet temperatures of the cooling water are measured using thermocouples. The adiabatic section of the heat pipe is completely insulated with asbestos rope and the heat losses from the evaporator and condenser surface is negligible. Four K-type thermocouples are placed on the outer surface of heat pipe at certain distance and two thermocouples at inlet and outlet of cooling water. All the temperature readings, at the four points on the heat pipe surface for inlet and outlet of cooling water are taken for all the working fluids and for all the fill ratios after reaching steady state condition.

Fig.4: Experimental Setup

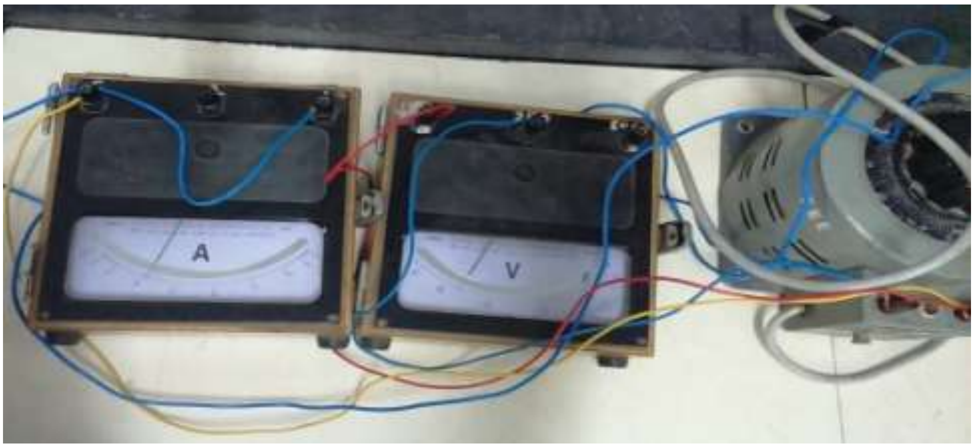

Fig.5: Readings noted from ammeter and voltmeter

4.2Experiment procedure

After power supply was turned on, the power was increased. The tests required approximately 15–25 min to reach a steady state. Once the steady-state condition had been reached, the temperature distribution along the heat pipe was measured and recorded, along with the other experimental parameters. Then the power input was increased incrementally, and the process repeated until dry out occurred as determined by rapid spikes in the evaporator thermal couple farthest from the condenser. Once dry out was reached, the temperature difference between the evaporator and condenser rapidly increased. The local heat pipe temperature was measured by using four isolated type- k thermocouples. All thermocouples are connected to a digital temperature recorder. Thermocouples (with the uncertainty lower than 0.1°C) are distributed along the surfaces of the heat pipe section as follows one thermocouple is attached to the centre at the evaporator section, two thermocouples are attached to the adiabatic section and one thermocouple is attached to the condenser section. One heater bar (maximum 90 W) was used as a heat source in the heating section. Thus, heating load (Q) and temperature differences (ΔT) were measured. The thermal resistance of the heat pipe can be determined by the flowing equation:

$$R=\frac{\Delta T}{Q}\left(\frac{k}{w}\right)$$

Thermal Conductivity: Thermal conductivity refers to the amount/speed of heat transmitted through a material. Heat transfer occurs at a higher rate across materials of high thermal conductivity than those of low thermal conductivity. Materials of high thermal conductivity are widely used in heat sink applications and materials of low thermal conductivity are used as thermal insulation.Thermal conductivity of materials is temperature dependent. The reciprocal of thermal conductivity is called thermal resistivity. Metals with high thermal conductivity, e.g. copper, exhibit high electrical conductivity. The heat generated in high thermal conductivitymaterials is rapidly conducted away from the region of the weld. For metallic materials, the electrical and thermal conductivity correlate positively, i.e. materials with high electrical conductivity (low electrical resistance) exhibit high thermal conductivity.

$$k=\frac{QL}{A\Delta T}$$

Where-Thermal conductivity is k in **W/m K**,

The amount of heat transfer through the material is Q in **J/S or W**,

The area of the body is A in m^2**,**

The difference in temperature is ΔT in **K**.

V. GRAPHS

Thermal resistance is a heat property and a measurement of a temperature difference by which an object or material resists a heat flow. Thermal resistance is the reciprocal of thermal conductance. Thermal resistance R in K/W is a property of a particular component. The readings noted while the process of experiment are calculated and graphs are plotted for average temperature distribution of the heat pipe versus input power and concentration of nanofluid.

5.1 Thermal Resistance at 0^0:

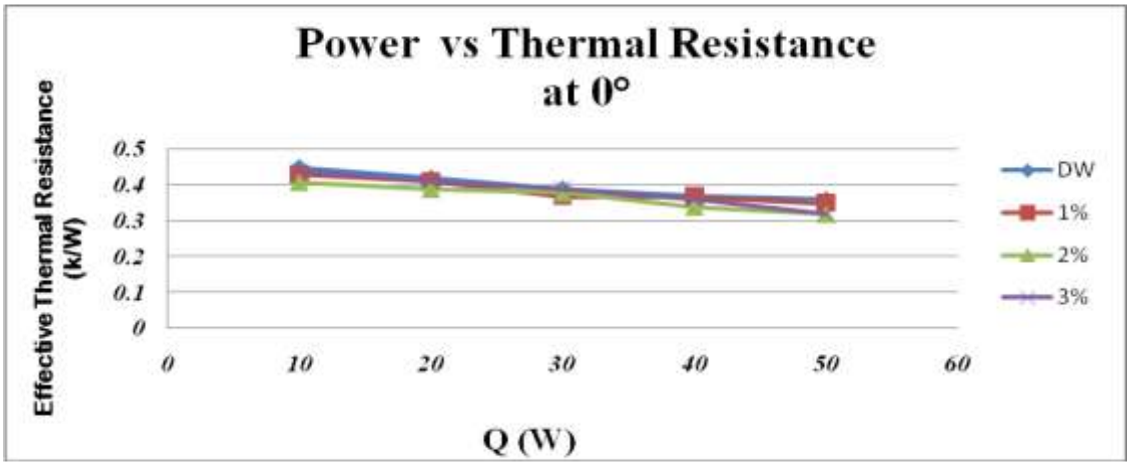

Fig.6: Performance of Thermal Resistance at 0^0Q vs ETR

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5.2 Thermal Resistance at 30^0:

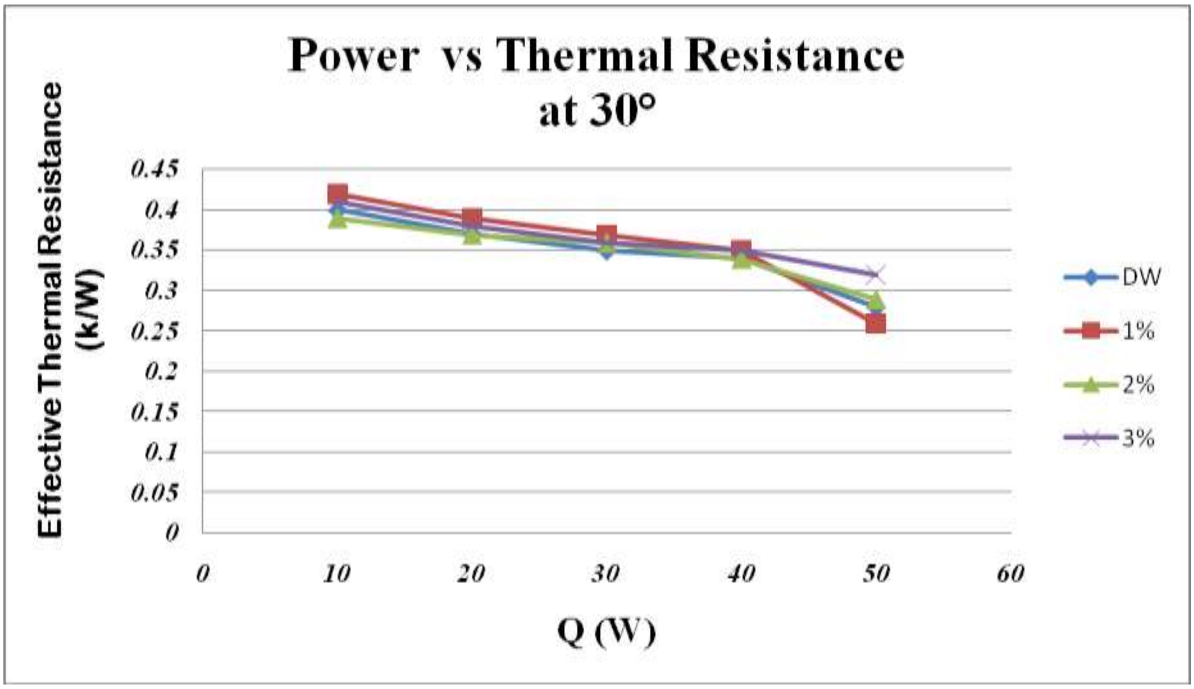

Fig.7: Performance of Thermal Resistance at 30^0Q vs ETR

5.3 Thermal Resistance at 60^0:

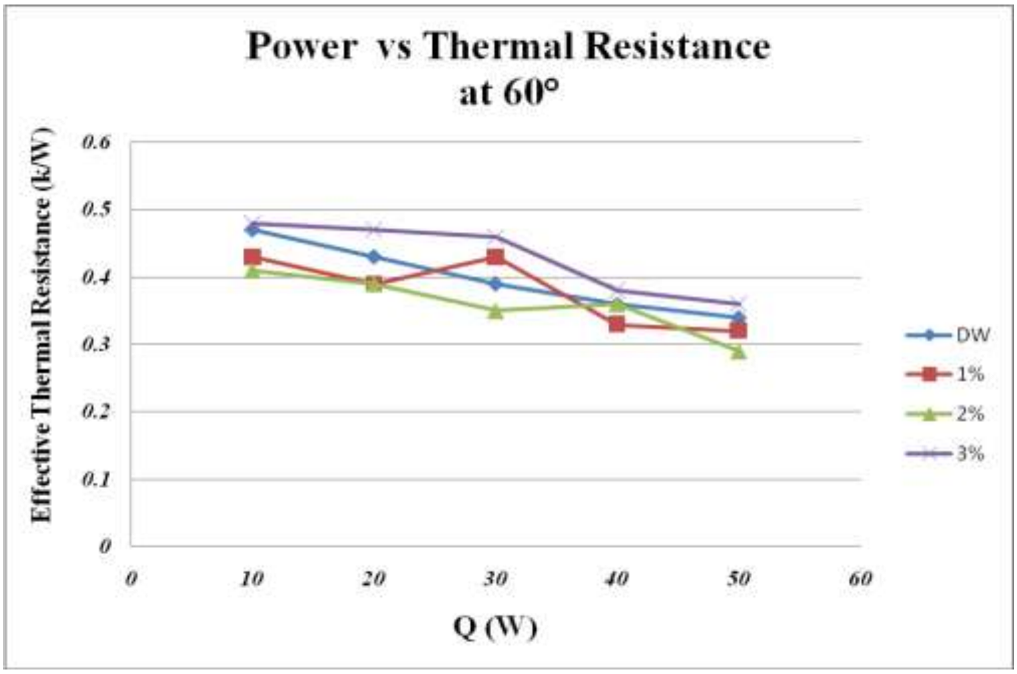

Fig.8: Performance of Thermal Resistance at 60^0Q vs ETR

5.4 Thermal Resistance at 90^0:

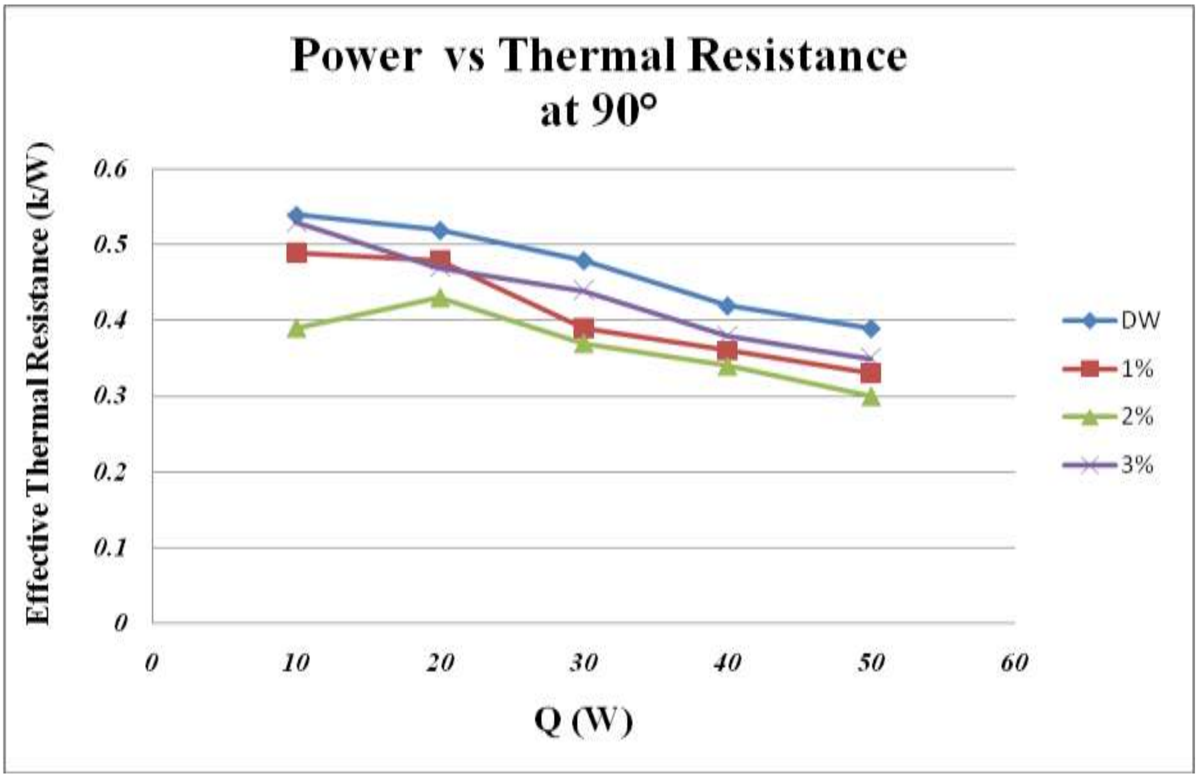

Fig.9: Performance of Thermal Resistance at 90^{0}Q vs ETR

5.5 Thermal Conductivity at 0^0:

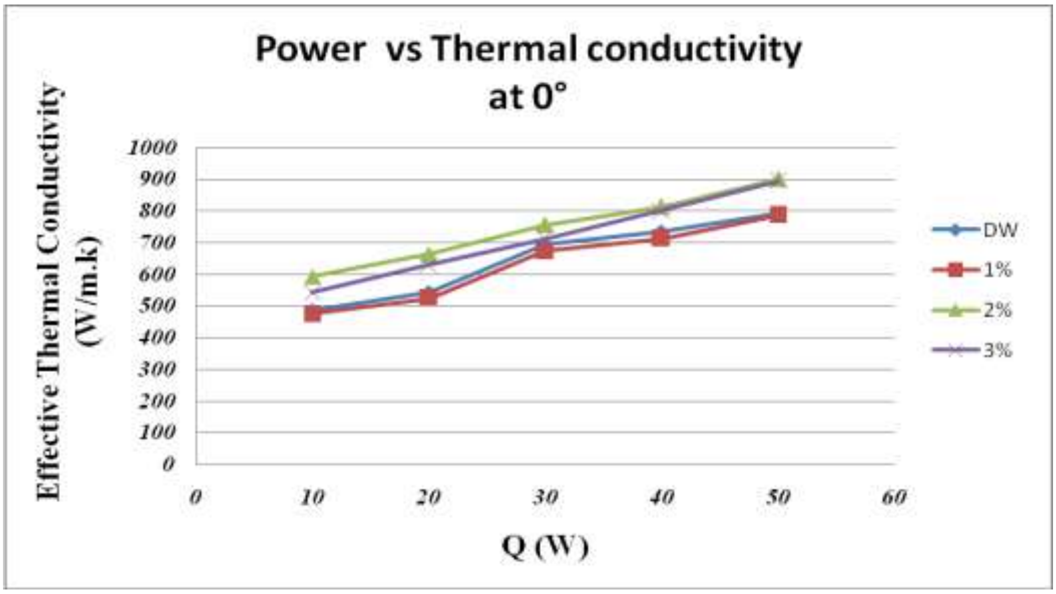

Fig.10: Performance of Thermal Conductivity at 0^{0}Q vs ETC

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5.6 Thermal Conductivity at 30^0:

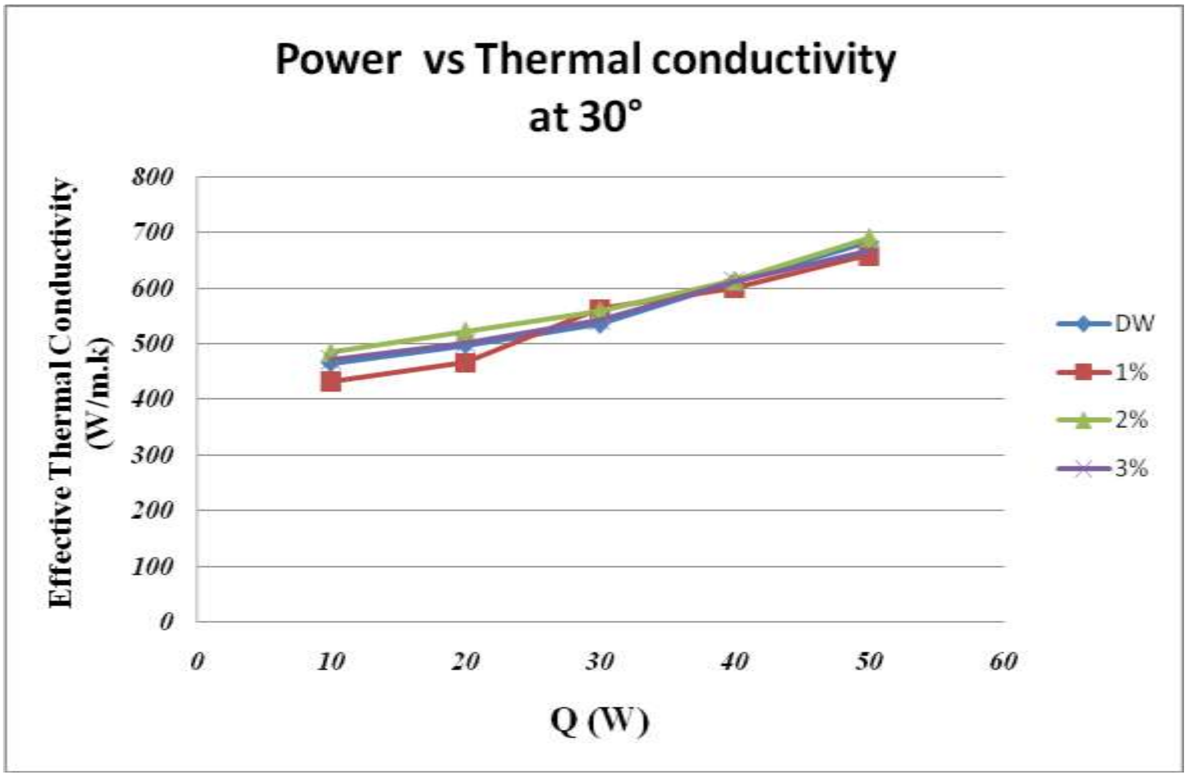

Fig.11: Performance of Thermal Conductivity at 30^0Q vs ETC

5.7 Thermal Conductivity at 60^0:

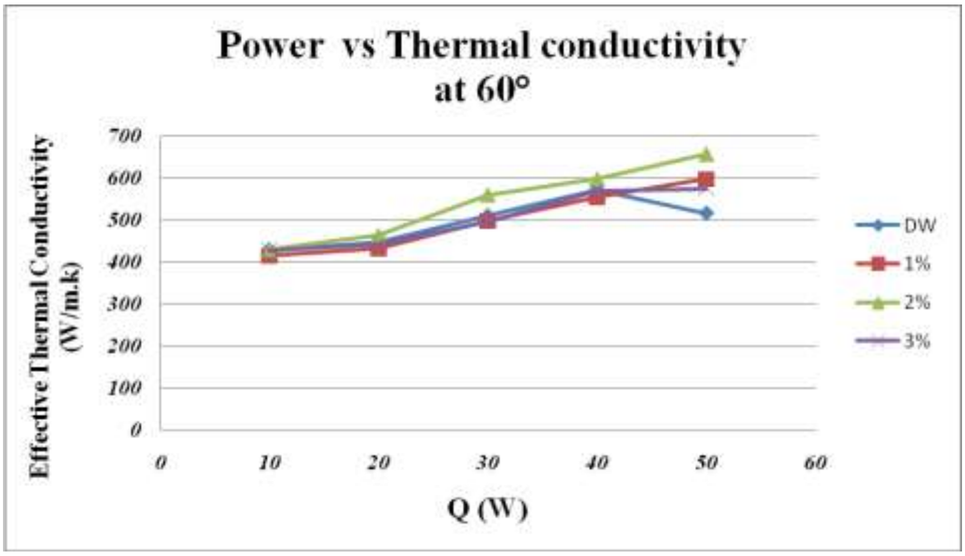

Fig.12: Performance of Thermal Conductivity at 60^0Q vs ETC

5.8 Thermal Conductivity at 90^0:

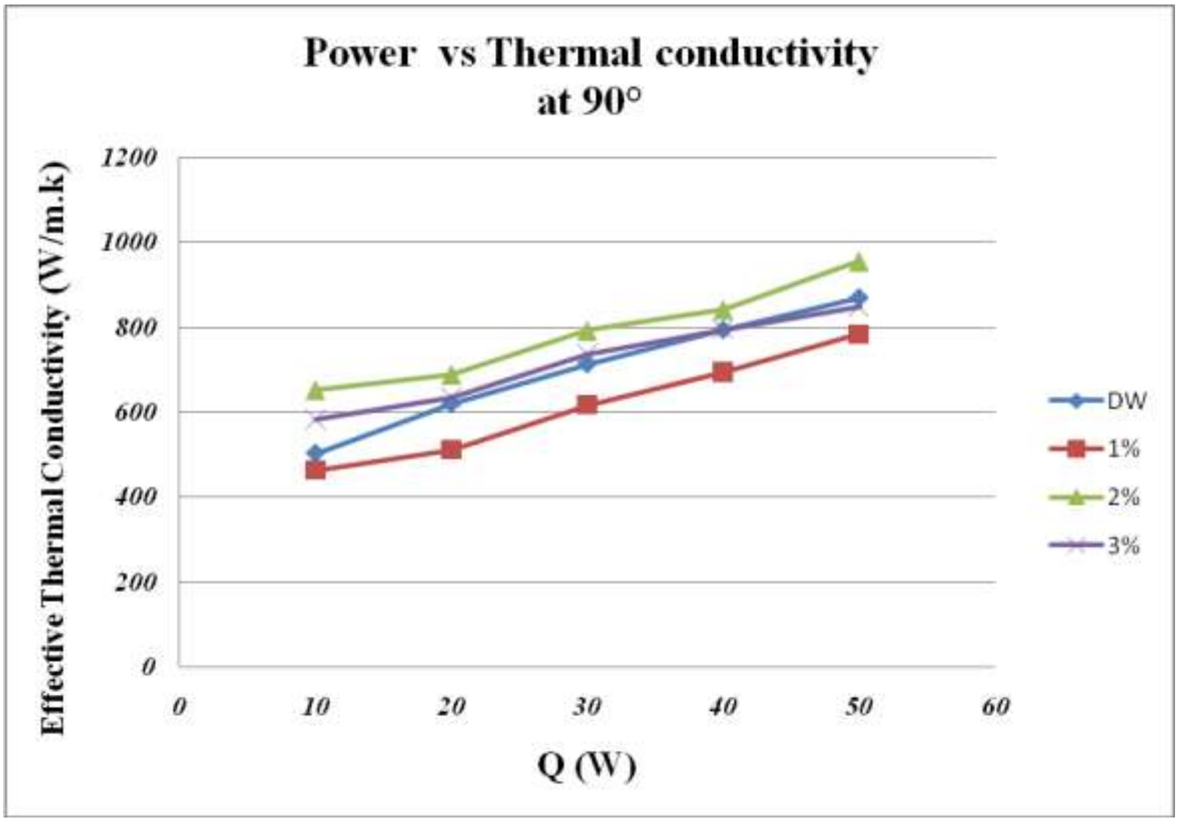

Fig.13: Performance of Thermal Conductivity at 90^0Q vs ETC

VI. CONCLUSION

An experimental study was performed to investigate the thermalperformance of screen mesh heat pipes using distilled water and water based CuONanofluids with mass concentrations of 1%, 2% and 3% as working fluids, focusing on heat pipes thermal behaviour by heat power input. The following conclusions are drawn from this study:

- The thermal performance of the heat pipe increases at 90^0utilizing 2wt% CuO NF while little bit of values decreases at 0^0, 30^0, 60^0 with 1wt%, 3wt% CuO NF compared with distilled water.
- Results indicate that the CuO nanofluid has remarkable potential as a working fluid for heat pipe of higher thermal prefaces.
- The thermal Resistance of the heat pipes with nanofluids is lower than that of pure water heat pipes.
- Results indicating that the thermal Resistance at 90^0 with 2wt% working fluid gave optimum values to flow on the heat pipe compared at 0^0, 30^0, 60^0, with1wt%, 3wt% CuO and distilled water.
- The thermal conductivity of the heat pipe are enhanced at 90^0utilizing 2wt% CuONanofluid decreases at 0^0, 30^0, 60^0 with 1wt%, 3wt% CuO NF compared with distilled water.
- The more CuO nanoparticle was dispersed in the working fluid. Hence the performances of heat pipe were enhanced.

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