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Research Article

Experimental Study of Al_2O_3 Nanofluids on the Thermal Efficiency of Curved Heat Pipe at Different Tilt Angle

S. Razvarz [1] **and R. Jafari** [2]

[1]*Departamento de Control Automatico CINVESTAV-IPN (National Polytechnic Institute), Mexico City, MEX, Mexico*
[2]*Centere for Artificial Intelligence Research (CAIR), University of Agder, 4879 Grimstad, Norway*

Correspondence should be addressed to S. Razvarz; srazvarz@yahoo.com

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This paper represents an experimental study about the effect of curves related to thermosyphons and heat pipes with different active fluids and inclination angle at the thermal efficiency. The nanofluid utilized in this work is an aqueous soluble of Al_2O_3 nanoparticles with 35 nm diameter in pure water. The test saturation level of nanoparticles is 0%, 1%, and 3%wt. All the experiments were conducted and repeated at inclination angle of 30°, 60°, and 90° (vertical). The article presents the gravity impacts on the heat transfer characteristics in different angles and the effects of working fluids and tilt angle of heat pipe tube by the addition of nanoparticles and weight fractions on the thermal efficiency of heat pipe at different inclination. According to the experimental results, the heat pipe at the tilt angle of 60° generates the superior results. At a particle volume concentration of 1%, the use of Al_2O_3/water nanofluid gives significantly higher heat transfer.

1. Introduction

Recently, the problem of heat dissipation from the electronic equipment is taken into consideration by using a new heat transfer devices such as heat pipe. Thermosyphons as well as heat pipes have been utilized in various applications related to the electronics industry which contains a superior speed and a high level of heat generation. Heat pipes are capable of transferring and removing the heat from a heat source over long distances. Heat pipes use the latent heat of vaporization of a working fluid to transfer heat.

Wei et al. [1] experimentally analysed the enhancement of thermal efficiency of grooved heat pipe charged with the silver nanoparticles and deionized water. Lin et al. [2] studied a research focusing on heat transfer of R141b and multiphase flow in a tube. Gao et al. [3] developed high efficiency in small heat pipes for high heat flux cooling. Ma et al. [4, 5] investigated the pulsating heat pipe charged with diamond nanofluids. In [6, 7], the authors have studied the results of axial rotational speed in heat pipes under steady-state operation. In [8, 9], the impacts of anisotropic shape and gravity of the conducting nanoparticle in nanofluid thermal conductivity have been studied. Liu et al. [10] considered the effects of vapor pressure at the critical values of the evaporator boundaries and length. In [11, 12], the positive effect over the nanofluid specifications based on the betterment of the thermal conductivity of liquids is considered and the effects of nanoparticle mean diameter on the heat transfer have been studied. Jang and Choi [13] checked numerically the cooling performance of a microchannel heat sink with nanofluid. Nguyen et al. [14] studied the increment of a particular nanofluid for cooling electronic components. Atmar and Zeinab [15] investigated extraction from clarified rumen fluid by modified magnetic nanoparticles. Nguyen et al. [16] evaluated the heat transfer behaviour of the water—Al_2O_3 and ethylene glycol—Al_2O_3 nanofluids in a heated tube. Hwang et al. [17, 18] measured kinematic viscosity, thermal conductivity, and thermophysical properties of nanofluids in heat transfer of the heat pipe. Kang et al. [19] added Ag pure water nanofluids in 1 mm wick-thickness sintered circular pipe to study the heat transfer performance of the heat pipe. He et al. [20] studied the methodology of heat-transfer phenomena and

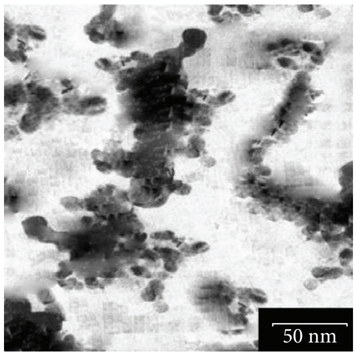

Figure 1: TEM photograph of Al_2O_3 particles.

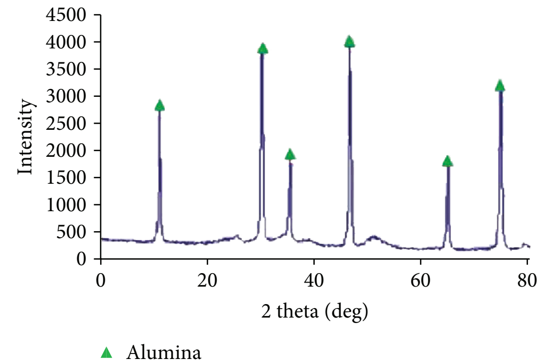

Figure 2: XRD Pattern of as-sprayed alumina nanoparticles.

flow behaviour of TiO_2 nanofluid with different particle sizes and concentrations upon upward flow through a vertical pipe. Moraveji and Razvarz [21] investigated on the outcome of Al_2O_3 nanofluids related to the thermal performance of the heat pipe; also, they demonstrated that more nanoparticles will cause a better performance in the heat pipe. Their results indicate that increasing the nanoparticle concentration and temperature could enhance the convective heat transfer coefficient of nanofluid. Saha et al. [22] studied the effect of process variables on the heat pipe; also, the observation reveals different operating ranges which depends on the loop orientation, filling ratio as well as input power. Asirvatham et al. [23] studied silver nanoparticles by dispersing in deionized water to improve heat transfer performance of a heat pipe. Xue and Qu [24] experimentally examined the effects of inclination angles to ammonia heat pipe and observed the thermal resistance increment or decrement. Batmani et al. [25] measured the effects of Al_2O_3 nanoparticle on the compression flow curve of AZ11 magnesium alloy and they showed that the nano-Al_2O_3 particulates improves the compressive yield strength of AZ11 magnesium alloy. Various researchers has been done studies principal measurement of thermal conductivity of nanofluids large number of exploratory and hypothetical [26, 27].

In the present study, the experimental results of the influence of Al_2O_3 nanofluid on grooved and curved heat pipes are studied. Furthermore, the comparison of the thermal performance of Al_2O_3 nanofluid with pure water is investigated. In continuation, the effects of nanoparticle volume percentage concentration and the gravitational effect is studied by placing evaporator at different orientation. As mentioned above, this paper presents the study on heat transfer in the curved heat pipe in an adiabatic section and the effect of heat pipe tilt angle that have rarely been reported. The results of this paper will be helpful in logical choice of acceptable percentage of nanoparticle in heat transfer.

2. Experimental Setup and Procedure

2.1. Characterization and Preparation of Al_2O_3 Nanofluids. The base working fluid is pure water in this experiment, and Al_2O_3 nanoparticles are the most common nanoparticles used with 30 nm and 45 nm in size measured by transmission electron microscopy (TEM). Figure 1 is the TEM photograph of Al_2O_3 nanoparticles with particle size about 35 nm which were added to pure water. The nanofluid used in this experiment is made of 99.0% pure aluminium oxide with an average particle size of 35 nm predispersed in water, and the precursors for its thermal deposition are trimethylaluminum (TMA) and water. XRD studies were also conducted to trace the conversion of Al_2O_3. Figure 2 shows the XRD pattern of the flame-sprayed nanoparticles. It can be seen from Figure 2 that Al_2O_3 were found in the as-sprayed nanoparticles. Al_2O_3 particles' true density is 3880 kg/m^3, which can be converted to weight fraction and volume fraction. The nanoparticles and pure water are mixed by utilizing an ultrasonic homogenizer with the concentration of 0, 1%, and 3% by weight. Al_2O_3 nanoparticles are generated by using a catalytic chemical vapor deposition technique. Aluminium oxide nanomaterials have been synthesized using precursors such as methane, acetylene, toluene, xylene, and benzene. As a matter of fact, one could use any type of hydrocarbon or carbonaceous materials for the synthesis of aluminium oxide nanomaterials.

2.2. Experimental Setup. The schematic diagram of the heat pipe under consideration is shown in Figure 3. The loop consists of a test section, cool water loop, and data recording system. The water flow at a constant rate is 1.7 L/min. The inlet temperature of the water is controlled and set at the temperature of $20 \pm 0.5^{\circ}$C by using a thermostatic bath in order to achieve a constant working temperature while the heat input increases. The closed loop of the evaporator contains cold water inside the storage tank having 0.125 m^3 volume and water pump. Experiments are carried out at various heat fluxes and three different tilt angles. The position of the heat pipe tilt angle is shown in Figure 4. The laboratory temperature is controlled at 25 $\pm 1^{\circ}$C. The heat pipe involved in the experiment is a straight copper tube with an outer diameter of 8 mm and a length of 190 mm that contains 1 mm wick-thickness copper powder (140–200 nm) sintered wicked. The studied heat pipe consists of three sections such as an evaporator, an adiabatic section, and a condenser. The condenser section of the flat heat pipe is inserted vertically into the cooling chamber to remove heat from the condenser section by forced convection to a constant temperature bath. For heating the evaporator section, a 0–220 V AC electric

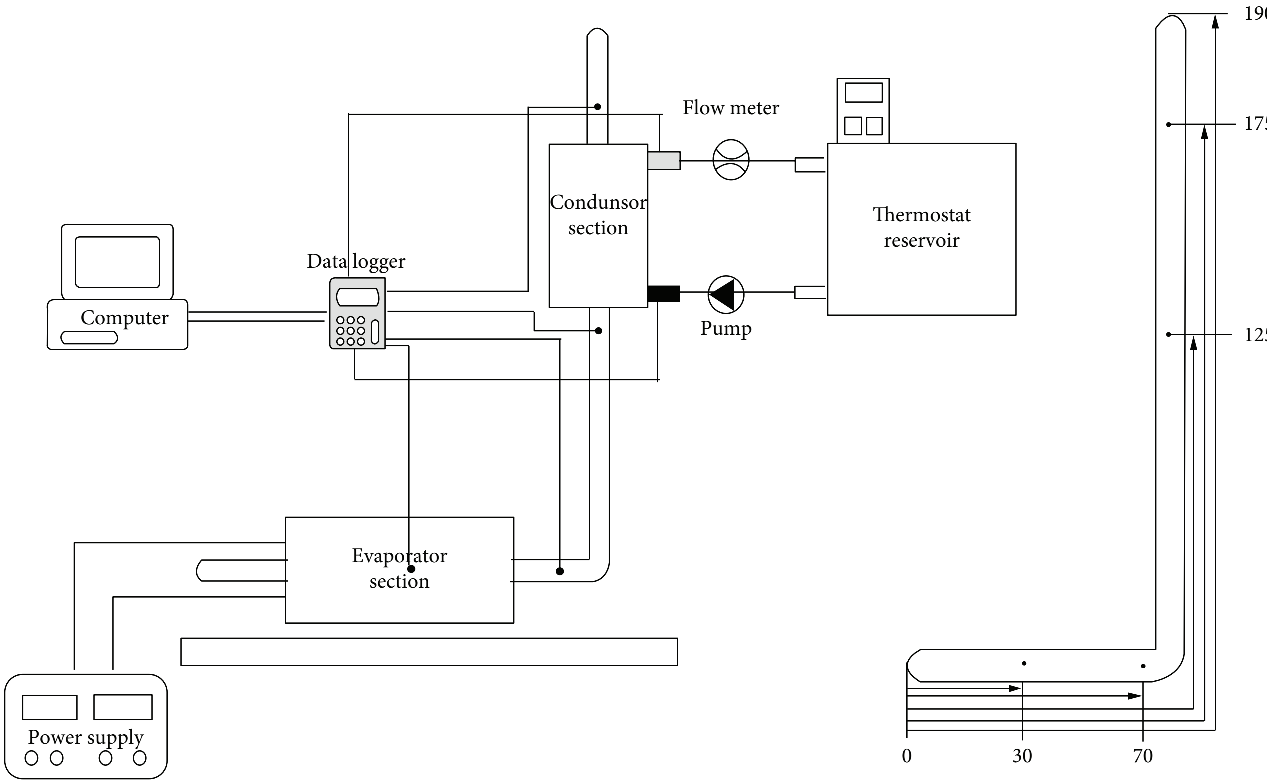

Figure 3: Schematics of the test setup.

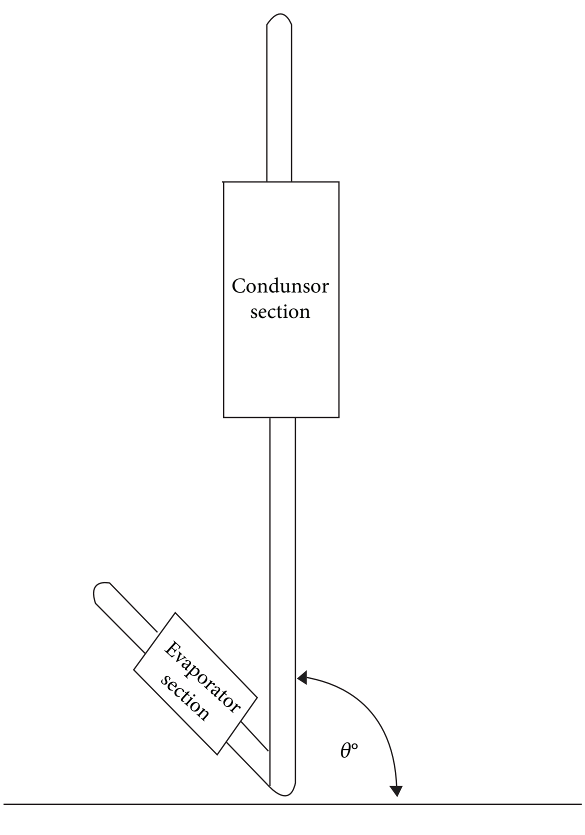

Figure 4: Position of tilt angle of the heat pipe.

heater is used. Electric power is obtained by measuring the current supplied to the electric heater and the voltage across the heating resistor. The electrical heater is glued with thermal grease master cooler HTX3-GL to decrease the contact thermal resistance between the heater and the heat pipe.

2.3. Test Procedure. The power supply is switched on initially, and then the power is increased. The tests require approximately 15–25 minutes to reach the steady state. In each step, the temperatures and other experimental parameters are recorded at the steady state conditions. Afterwards, the power input is increased, and so the process is iterated until the occurrence of dry out as found out by rapid spikes in the evaporator thermal couple which is far from the condenser. Once dry out is attained, difference between temperature of the evaporator and condenser increases rapidly.

The local temperature is measured by using four isolated type T thermocouples. Thermocouple signals are recorded by a data logger (Fluke, Hydra Series II) with the uncertainty lower than 0.1°C. Thermocouples are distributed along the surfaces of the heat pipe section as follows: one thermocouple is attached to the condenser section, two thermocouples are attached to the adiabatic section, and one thermocouple is attached in the middle of evaporator section. Through record and calculation, the ratio of removed energy of cooling water by condenser section to the heating power by evaporator section with different weight fraction of nanoparticle, and tilt angle of heat pipe, the effects of thermal efficiency under different

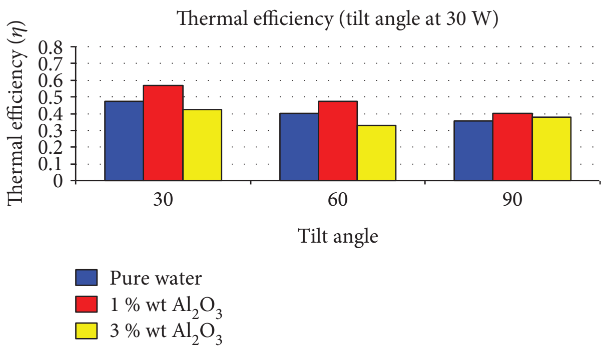

Figure 5: Alteration of thermal efficiency of heat pipes by various tilt angles and fluids of heat pipes at 30 W power.

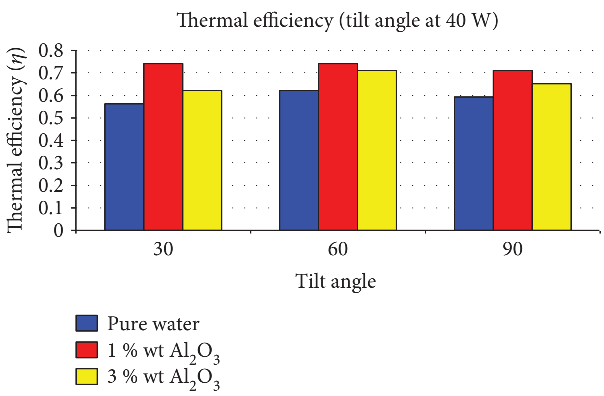

Figure 6: Alteration of thermal efficiency of heat pipes by various tilt angles and fluids of heat pipes at 40 W power.

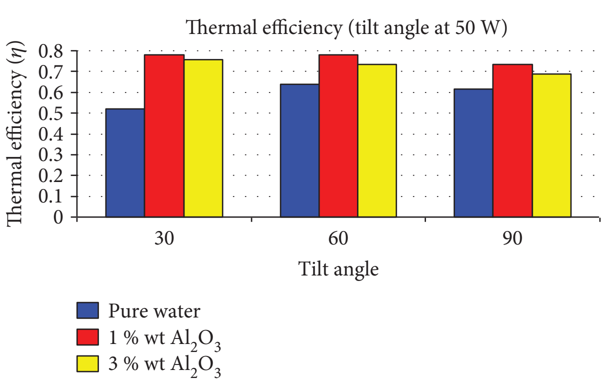

Figure 7: Alteration of thermal efficiency of heat pipes by various tilt angles and fluids of heat pipes at 50 W power.

tilt angle and nanofluid can be evaluated. The heat pipe efficiency can be calculated as follows:

$$\eta = m_w C_p \frac{(T_{\text{wout}} - T_{\text{win}})}{(V.I)}. \quad (1)$$

3. Results and Discussion

The enhancement of convective heat transfer coefficient depends on increasing of the fluid thermal conductivity.

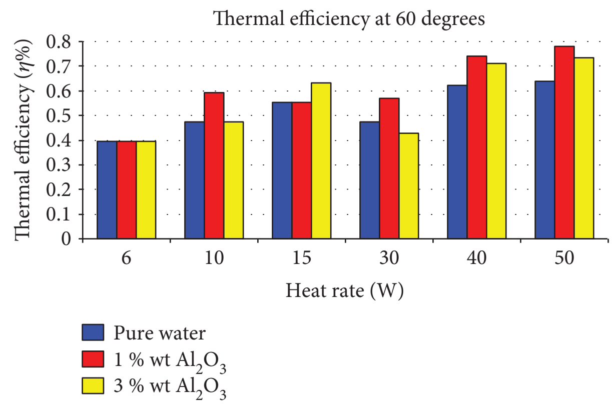

Figure 8: Variations of thermal efficiency in different heat rate at 60° tilt.

Thermal conductivity of the nanofluids increases with increasing of the volume concentrations. Adding nanoparticles to liquid strikingly improves energy transport process of the base liquid. A smaller particle size would provide a much larger surface area for molecular collisions and therefore increase the rate of reaction, making it a better catalyst and reactant.

The form of heat pipe, working fluid, and effect of gravity has a considerable effect on its efficiency. In this experiment, several conditions for fluid is taken into consideration, in order to measure the temperature distribution of heat pipe as well as cooling water the evaporator and condenser.

In vertical mode, the vapor bubbles which take up heat in the evaporator grow in size. Their own buoyancy helps them to rise up in the tube section. The rising bubbles in the tube is a natural tendency for the liquid slugs to travel downwards, helped by gravity force, toward the evaporator. In horizontal mode (90° inclination angle) of operation, there was hardly any macromovement of bubbles. This strongly suggests that gravity does play a role in the heat pipe. Since gravity force is ineffective, all the movement of bubbles and slugs has to be necessarily done by the pressure forces. These forces are created due to temperature difference, which exists between evaporator and condenser.

Figures 5 and 6 as well as Figure 7 display the alteration of thermal efficiency related to the heat pipe. By utilizing fluids with various concentration percent of Al_2O_3 nanoparticles at 30, 60, and 90 tilt angles, different results can be obtained. The increment of tilt angle will cause the enhancement of flow back into the evaporator section. By increment the tilt angle from 0 to 60, the thermal efficiency increases, but if the increment is more than 60°, the thermal efficiency will decrease. The reason is that the effect of gravitational force between the evaporator section and the condenser section is increased. On the other hand, when the tilt angle of heat pipe is taken to be constant, then by adding nanoparticles to the base fluid, the efficacy of thermal conductivity will be increased. The addition of more nanoparticles to fluid causes the property of working fluid at the evaporator section to convert into the solid phase. Also, it results in the decrease of the convection performance of nanofluid inside the

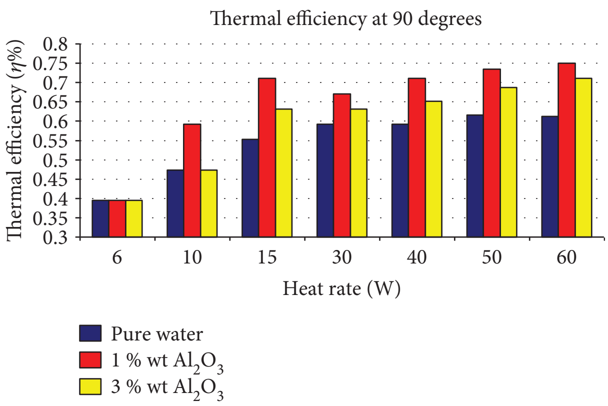

Figure 9: Variations of thermal efficiency in different heat rate at 90° tilt.

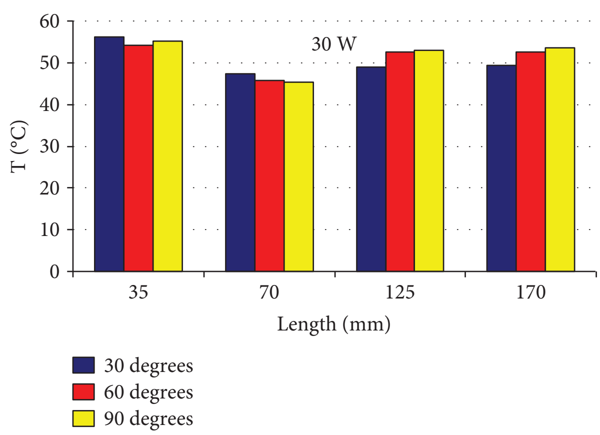

Figure 10: Temperature of heat pipe diffusion in different tilt angles of heat pipes at 1.0 wt. % under 30 W input power.

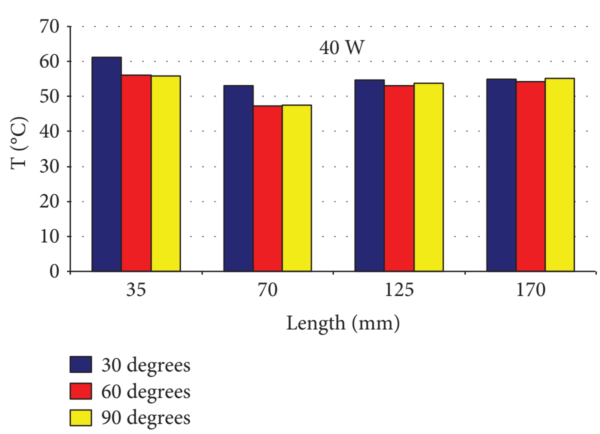

Figure 11: Temperature of heat pipe diffusion in different tilt angles of heat pipes at 1.0 wt. % under 40 W input power.

evaporator section. Figures 8 and 9 display that at constant angle of the heat pipe, by the increment of heat rate, the heat pipe efficiency will be increased. In these figures, it can be

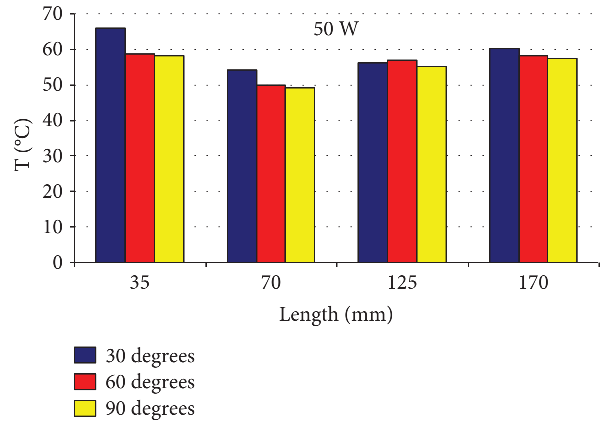

Figure 12: Temperature of heat pipe diffusion in different tilt angles of heat pipes at 1.0 wt.% under 50 W input power.

seen that after the tilt angle of 60° (Figure 8), the heat pipe efficiency has been decreased. The temperatures of heat pipe diffusion have been shown in Figures 10–12 in various tilt angles of heat pipes at 1.0 wt % concentration under different input power.

As can be seen, increasing the contact angle causes the condensed vapor to return faster to the evaporator section by means of gravity, and consequently, lower thermal resistances and higher heat transfer coefficients were obtained.

4. Conclusions

In this paper, an experimental research of the thermal enhancement related to the heat pipe is carried out proficiently by adding Al_2O_3 nanopowder to pure water in side 1 mm wick-thickness sintered circular heat pipe in various tilt angles. The gravity effects on the heat transfer in the heat pipe have been experimentally studied in the paper by four kinds of test orientations.

Important conclusions have been obtained and are summarized as follows:

(i) The ideal value of thermal efficiency obtains at the concentration of 1.0% wt nanofluid.

(ii) The heat transfer coefficient increases with increasing the applied heat flux at the evaporator.

(iii) Adding Al_2O_3 nanoparticles to pure water could enhance the thermal efficiency of heat pipe.

(iv) With enhancement of the heat flux, the heat pipe efficiency tends to increase.

(v) In this experiment, the thermal efficiency of the heat pipe with 0.1% nanoparticle volume concentration is higher than other fluids with different nanoparticle volume concentration.

(vi) Effects of heat pipe tilt angle on the thermal efficiency are checked and is shown that it can be increased at higher tilt angle.

(vii) The inclination angle has a great effect on the heat pipe thermal resistance using water as the working fluid.

(viii) The heat pipe thermal efficiency get enhanced with increasing nanoparticle concentrations and tilt angles.

(ix) The heat pipe thermal efficiency of the nanoparticle fluids decreases when the heat pipe tilt angle is 60°.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

This paper is an extension version of the work originally presented in [28].

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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