

Thermal Performance of Screen Mesh Wick Cylindrical Heat Pipe using Al₂O₃ Nanofluid

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ABSTRACT: In this research, the effect of using aluminum oxide Nanofluid (pure water mixed with Al₂O₃ nanoparticle With 35 nm diameter) on the thermal efficiency enhancement of a heat pipe on the different operating state was investigated. The heat pipe was made of a straight copper tube with an outer diameter of 8mm and length 190 mm and stainless steel of 1mm wick-thickness for heat pipe. In the heat pipe tube, there is a 90° curve between the evaporator and condenser sections. The tested concentration levels of Nanofluid are 0%, 1% and 3%wt. Results show that by charging the Nanofluid to the heat pipe, thermal performance is enhanced by reducing the thermal resistance and wall temperature difference. The thermal efficiency of heat pipe charged with Nanofluid is compared with pure water.

KEYWORDS: Heat pipe, Nanofluid, Thermal performance, Heat load.

I. INTRODUCTION

Generally, a heat pipe is a heat mover or heat spreading device and it acquires heat from a source and transfers or spreads it to a sink region. The heat transfer ability is the most important factor, and it has to be designed to maximize with various influencing parameters. It needs very little drop in temperature to move this heat. Typically the heat pipe is a simply sealed and vacuumed tube with a porous wick structure to generate capillary force. The heat pipe has mainly three connected sections: evaporator, adiabatic section and condenser. Various parameters to maximize heat transfer ability of a heat pipe are influenced by working fluids such as nanofluid, pumping pressure, friction loss toward length, charging ratio and inclination angle. If there is no structural change in the heat pipe such as porous wick, container, orientation, diameter, length and so on, the working fluid is the main solution to improve the heat transfer performance of heat pipe. The correct choice of working fluid is the important design factor which can lead to decrease the thermal resistance of a heat pipe. In recent days, nanofluid as the new working fluids of heat pipe have been tried to be adopted as the heat transfer fluid. Nanofluid are a new class of heat transfer fluids that 1% or less of particles, fibers, or tubes with lengths on the order of 1-50 nm are stably suspended in traditional heat transfer fluids such as water, alcohol, etc.

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.

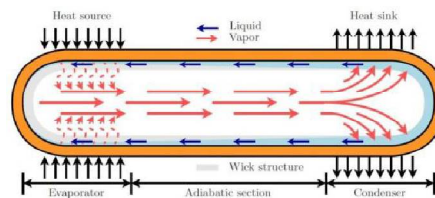


Fig: 1: Heat pipe principle

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 fibre 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,

III. EXPERIMENTAL ANALYSIS

A. 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 8 and 190 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 electrical heater was attached with thermal grease (master cooler–HTX3-GL) to reduce the contact thermal resistance between the heater and the heat pipe surface.



Fig: Readings noted from ammeter and voltmeter



Fig: Experimental Setup

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% 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

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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.

B. EXPERIMENT 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:

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

IV. SAMPLE CALCULATIONS

Thermal Resistance (R)

Effectiveness of heat pipe is indirectly brought in terms of thermal resistance

$$R = \frac{t_e - t_c (^{\circ}C)}{Q(W)}$$

Where t_e - evaporator temperature

t_c - condenser temperature

R - Thermal resistance

Q - Heat flux

Sample calculation of R at 6W for pure water

From the readings: $t_e = 49^{\circ}C$; $t_c = 48^{\circ}C$; $Q = 6W$

Thermal resistance of heat pipe:

$$R = \frac{t_e - t_c (^{\circ}C)}{Q(W)} = \frac{49 - 46 (^{\circ}C)}{6(W)} = \frac{3 (^{\circ}C)}{6(W)} = 0.5 \frac{^{\circ}C}{W}$$

Sample calculation of R at 6W for 1% Al_2O_3 :

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From the readings: $t_e = 47^\circ\text{C}$; $t_c = 45^\circ\text{C}$; $Q = 6\text{W}$

Thermal resistance of heat pipe:

$$R = \frac{t_e - t_c(^{\circ}\text{C})}{Q(\text{W})} = \frac{47 - 45(^{\circ}\text{C})}{6(\text{W})} = \frac{2(^{\circ}\text{C})}{6(\text{W})} = 0.33 \frac{^{\circ}\text{C}}{\text{W}}$$

Sample calculation of R at 6W for 3% Al_2O_3 :

Thermal resistance of heat pipe:

From the readings: $t_e = 45^\circ\text{C}$; $t_c = 44^\circ\text{C}$; $Q = 6\text{W}$

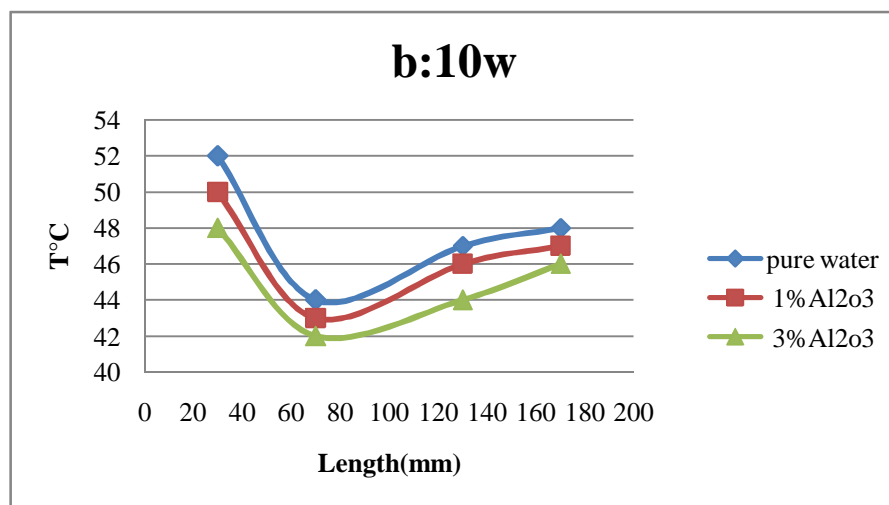
$$R = \frac{t_e - t_c(^{\circ}\text{C})}{Q(\text{W})} = \frac{45 - 44(^{\circ}\text{C})}{6(\text{W})} = \frac{1(^{\circ}\text{C})}{6(\text{W})} = 0.16 \frac{^{\circ}\text{C}}{\text{W}}$$

The above procedure is applicable for all the remaining R values at different watts of different heat inputs of working fluid.

V. EXPERIMENTAL RESULTS

A. THERMAL RESISTANCE (TR):

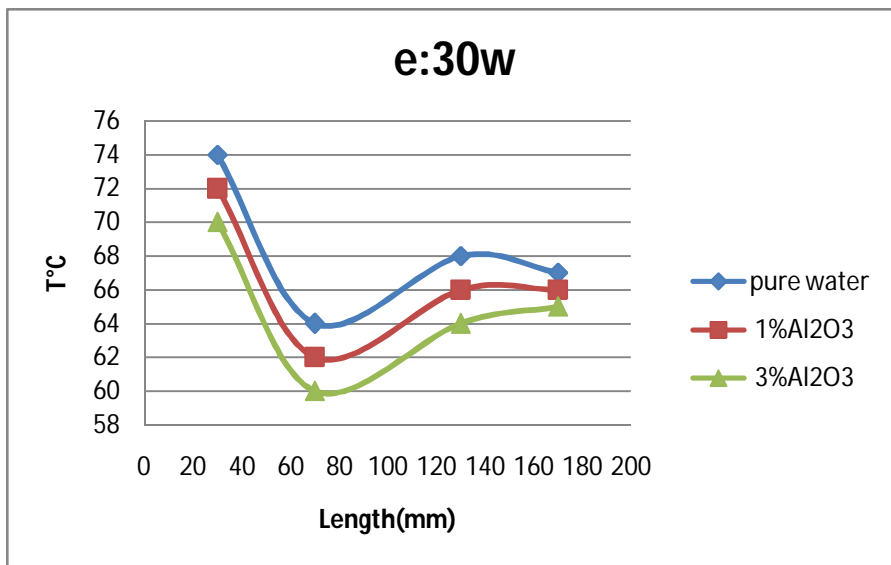
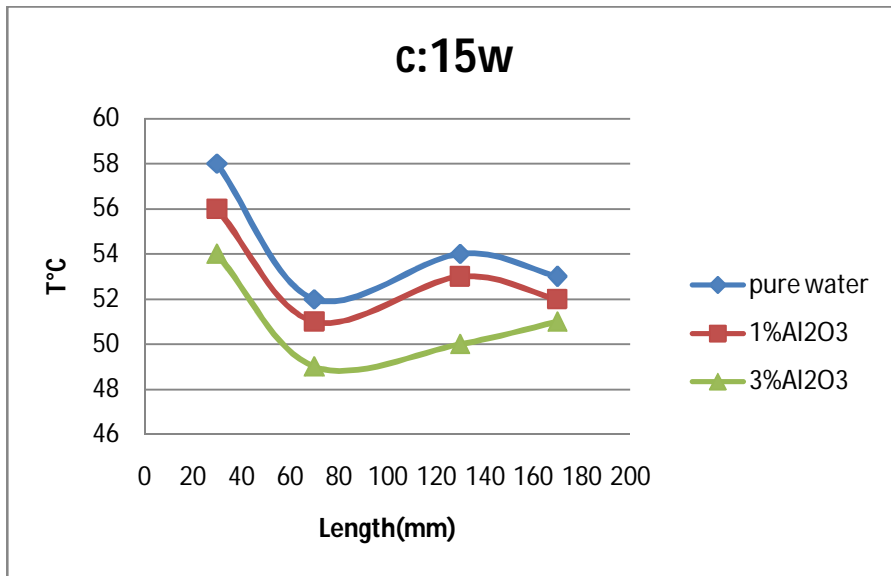
Thermal resistance is a heat property and a measurement of a temperature difference by which an object or material resists a heat flow. Thermal resistance is the reciprocal of thermal conductance. Thermal resistance R in K/W is a property of a particular component. The readings noted while the process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



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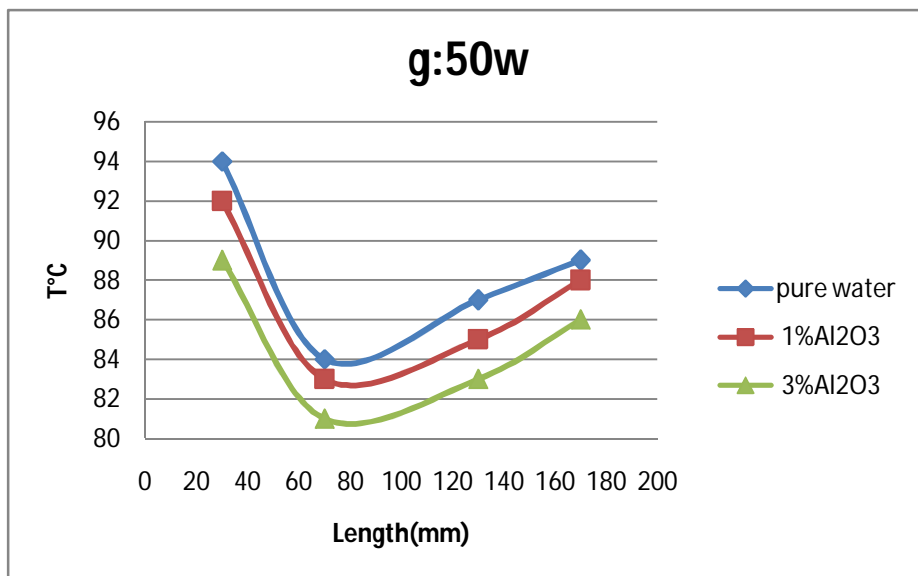
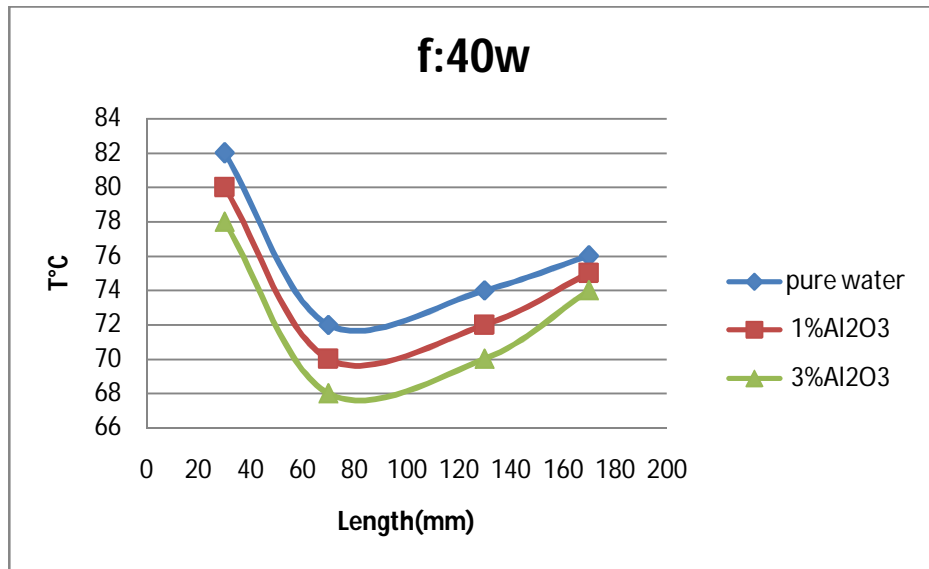
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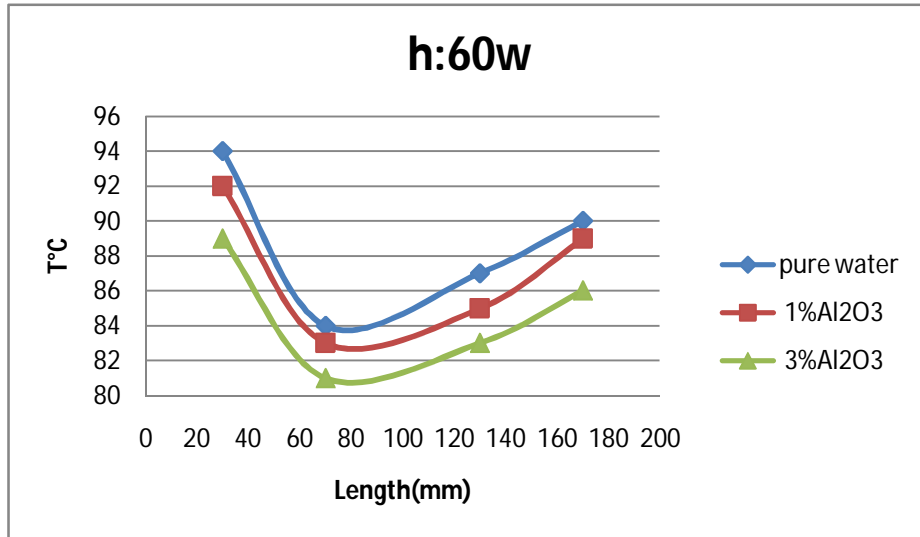


Fig: Average temperature distribution of the heat pipe versus input power and concentration of nanofluid

VI. RESULTS AND DISCUSSIONS

The shape of the heat pipe and working fluid has a significant effect on its performance. Therefore, the presented experiments consider various conditions of fluid, in order to measure the distribution of heat pipe that the condenser and evaporator is perpendicular line pipe presents the wall temperature distribution versus the length of the heat pipe under the different power inputs and Al₂O₃ Nanofluid concentration. As seen in these figures, by increasing the input power, the wall temperature is increased.

In heat pipe with charged Nanofluid as the working fluid, the wall temperature decreased with respect to pure water thus providing a better performance. Also with higher concentrations of the nanofluid, wall temperature decreased. As a case for discussion, for example in 30 W, the distributions of wall temperatures of the heat pipe with pure water were 74, 64, 68 and 67 °C and for those containing 1% wt. Al₂O₃, these were 72, 62, 66 and 66 °C and for 3% wt. Al₂O₃, these were 70, 60, 64 and 65 °C respectively.

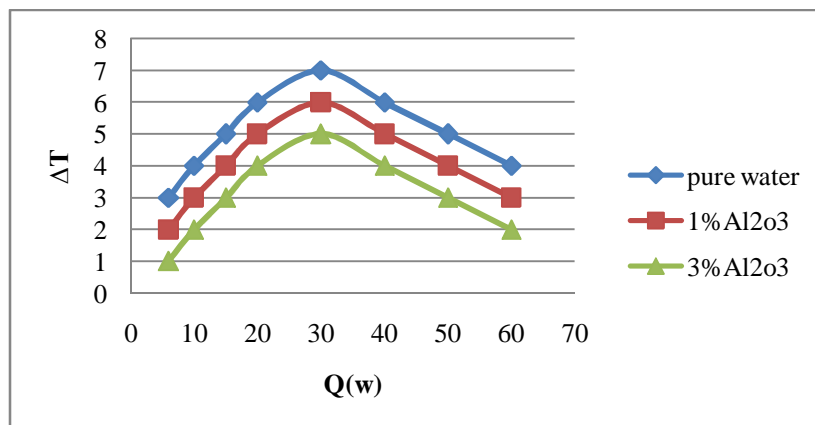


Fig: Effect of nanoparticle concentration on the temperature difference of heat pipe under different input powers.

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Then the influences of the nanoparticle concentration level on the temperature difference of the heat pipe under various input powers. From this figure it can be seen that by increasing the Nanofluid concentration, the temperature difference decreased. Also be seen this is the reason the value of vapour and rate of transnational speed between condenser and evaporator improved. It can be seen that for a constant temperature difference, the use of a Nanofluid as the working fluid allows the heat pipe to operate under a larger heat load shows the effect of the Nanofluid concentration on the thermal resistance of heat pipe versus heat pipe heat load. Results of charging the working fluid with Nanofluid are compared with that of pure water. With charging the Nanofluid as working fluid, the thermal resistance of the heat pipe decreased. It can be seen that increasing the nanoparticle concentration decreases the heat pipe thermal resistance and provides a better performance.

The reason for reducing the thermal resistance of the heat pipe can be explained as follows. Reducing the thermal resistance of heat pipe is caused by the formation of a vapour bubble at the liquid–solid interface. A larger bubble nucleation size creates a higher thermal resistance that prevents the transfer of heat from the solid surface to the liquid. The suspended nanoparticle tends to bombard the vapour bubble during bubble formation. Therefore, it is expected that the nucleation size of the vapour bubble is much smaller for the fluid with suspended nanoparticle than the fluid without.

VII. CONCLUSIONS

This paper deals with the thermal enhancement of the heat pipe performance by charging Al₂O₃ Nanofluid as the working fluid inside a 1 mm wick-thickness Stainless steel heat pipe which is experimentally tested.

- The more Al₂O₃ nanoparticle was dispersed in the working fluid, the performance of heat pipe were enhanced.
- Results indicate that the Al₂O₃ Nanofluid has remarkable potential as a working fluid for heat pipe of higher thermal prefaces.
- The thermal resistance of the heat pipes with nanoparticle solution is lower than that of pure water in heat pipes.

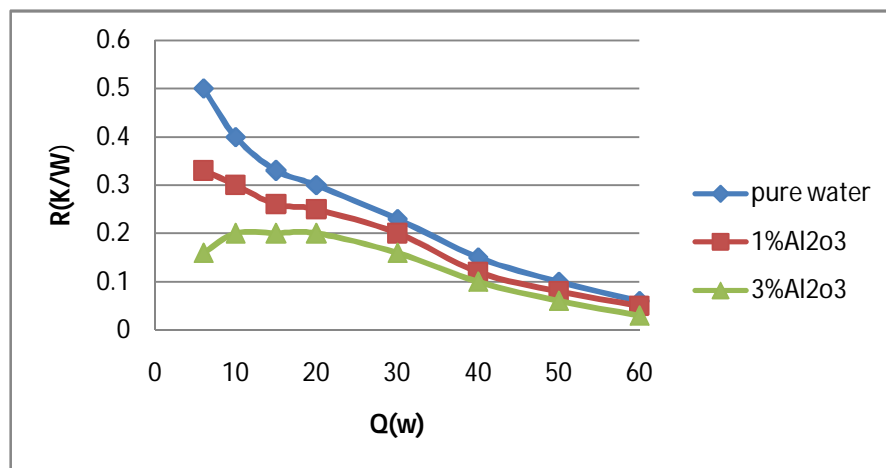


Fig: The effect of different nanoparticle concentrations and input powers on the heat pipe thermal resistance.

- There is a sudden drop in the curved zone along the tubes because of the vapour's impact and the lack of transfer which is inside the pipe itself.

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- The lowest temperature in the heat pipe can be observed in the curved zone and this temperature decreases from the evaporator to the curve and then increases.

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