

Thermal Performance of a Square Copper Heat Pipe for Different Volumes of CuO Nanofluid

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ABSTRACT: In this paper, Thermal performance of a square copper heat pipe for different fill ratios using CuO as a working fluid with Distilled water as its base fluid is determined. The square heat pipe is fabricated using copper tube of 300mm length and 19mm inner diameter and 22mm outer diameter which contains three sections: evaporator, adiabatic and condenser sections. A copper screen mesh with 100holes per inch is used to generate capillary pressure and to distribute the liquid around the evaporator area. A closed heater of capacity 150w is made of galvanized sheet and filament is used for providing the required heat source at the evaporator section. CuO is used as a working fluid due to its high boiling point, density and melting point. The performance of square heat pipe is measured in terms of thermal resistance and over all heat transfer coefficient. The amount of working fluid filled in different fill ratios used in this experiment were 25, 50, 75 and 100 percentage of the evaporator volume for all different quantities of working fluids. The temperature distribution is measured by using K-type thermocouples on the surface of the square heat pipe. For CuO thermal resistance is minimum value and over all heat transfer is maximum value with different fill ratios and heat inputs.

KEYWORDS: Square heat pipe; Copper screen mesh; Different fill ratios; Thermal resistance; over all heat transfer coefficient; Tilt angle; Working fluid.

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 nanofluids, 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, nanofluids as the new working fluids of heat pipe have been tried to be adopted as the heat transfer fluid. Nanofluids 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.*

The heat pipe was originally invented by Gurgler of the General Motors Corporation in 1942, but it was not, however, until its independent invention by Grover in the early 1960s that the remarkable properties of the heat pipe became appreciated and serious development work took place. Heat pipes were developed especially for space applications during the early 60' by the NASA. One main problem in space applications was to transport the temperature from the inside to the outside, because the heat conduction in a vacuum is very limited. Hence there was a necessity to develop a fast and effective way to transport heat, without having the effect of gravity force. The idea behind is to create a flow

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field which transports heat energy from one spot to another by means of convection, because convective heat transfer is much faster than heat transfer due to conduction.

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.

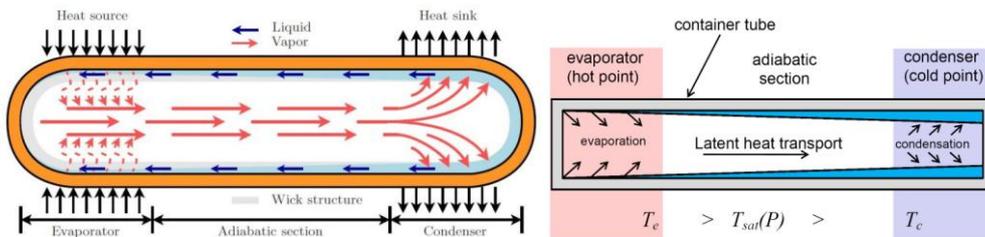


Fig. 1: Heat pipe principle

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, thermo physical properties and compatibility.

2. PARAMETICAL STUDY

2.1. Effect of Copper Square Heat Pipe and heater

Copper has many desirable properties for thermally efficient and durable heat exchangers. Copper is an excellent conductor of heat. Due to its high thermal conductivity allows heat to pass through it quickly. Other desirable properties of copper in heat exchangers include its corrosion resistance, bio-fouling resistance, maximum allowable stress and internal pressure, creep rupture strength, strength, hardness, thermal expansion, specific heat, antimicrobial properties, tensile strength, yield strength, high melting point, alloy ability, ease of fabrication, and ease of joining. The copper heat pipe with closed heater is shown in below Fig. 2.

Galvanized iron sheet is used to make heater for evaporator section. Due to its light weight and corrosion free resistance this is used in experiment. It transfers heat to the heat pipe when the power supply is given to the heater i.e. electrical energy is converted into heat. The heater used in the experiment is shown in Fig. 3.



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Fig. 2. Copper heat pipe with closed heater

Fig. 3. Square heater

2.2. Effect of Working Fluid

Working fluid is selected based on the properties of the fluid which has the ability to transfer heat and must have compatibility with wick and wall materials. It should have good thermal stability, high latent heat, high thermal conductivity, high surface tension, low vapour and liquid viscosities. Due to this copper is chosen as working fluid in this experiment. The amount of distilled water mixed with CuO is mentioned in table 1.

As copper is a Block D of Period 4 element, while oxygen is a Block P of Period 2 element, Copper oxide nanoparticles is in brownish-black powder. Copper (II) oxide or cupric oxide shown in Fig. 4 is the inorganic compound with the formula CuO.

It is formed by heating copper in air at around 300 - 800°C.



Fig. 4. Copper oxide nano powder

TABLE 1 CUO MIXED WITH DISTILLED WATER

Sl. No	Fill Ratios	Quantity
1	Cuo as working fluid with 25% fill ratio	Distilled water + 0.1g of Cuo
2	Cuo as working fluid with 50% fill ratio	Distilled water + 0.2g of Cuo
3	Cuo as working fluid with 75% fill ratio	Distilled water + 0.3g of Cuo
4	Cuo as working fluid with 100% fill ratio	Distilled water + 0.4g of Cuo

2.3. Effect of Copper Wire Mesh

The soft and malleable properties of copper metal make it ideal for woven wire mesh and wire cloth. It is often used in industry for its properties of high electrical conductivity and thermal conductivity as it conducts heat up to eight times better than other commonly used metals. Other benefits are versatility, tensile strength, low thermal expansion, biostatic. The Fig. 5 shows the copper screen mesh used in the experiment which consists of 100 holes per inch.

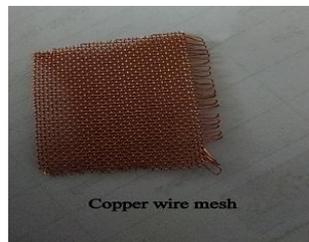


Fig. 5. Copper wire mesh

III. EXPERIMENTAL METHOD

The square heat pipe is fabricated using copper tube of 300mm length and 19mm inner diameter and 22mm outer diameter which contains three sections: evaporator, adiabatic and condenser sections as shown in table 2. A closed heater of capacity 150w is made of galvanized sheet and filament is used for providing the required heat source at the evaporator. The adiabatic section is insulated with asbestos rope to minimize the heat losses through the portion. The

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condenser section is cooled by circulating water at constant temperature and flow rate. Acrylic pipe is attached by using araldite. The wick material is copper with 100holes per inch.

TABLE 2 DIMENSIONS OF SQUARE HEAT PIPE

Sl. No	Section	Outer Diameter (mm)	Inner Diameter (mm)	Length (mm)
1	Evaporator	22	19	100
2	Adiabatic	22	19	100
3	Condenser	22	19	100

The wall temperature distribution of the heat pipe is measured using K-type thermocouple wires with an uncertainty of $\pm 1^\circ\text{C}$. A simple 6-channel digital temperature indicator is used to measure the temperature. Experiments are conducted with different fill ratios of working fluid and various plots are drawn to study the performance of miniature heat pipe to optimize the fluid inventory. The vacuum is maintained in the heat pipe to remove the impurities by opening the pressure release valve.

IV. EXPERIMENTAL ANALYSIS

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 Fig. 6. The heat pipe is charged with 25%, 50%, 75% and 100% of working fluid. A layer of copper mesh wick is used in the inner wall of the heat pipe to provide capillary pumping force of the working fluid and a coarse mesh to support and maintain the structural integrity of the vapor 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.

Three K-type thermocouples are placed on the square heat pipe 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 three points on the heat pipe surface and fourth and fifth are 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.

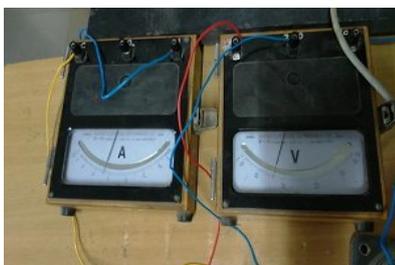


Fig.6. Readings noted from ammeter and voltmeter Fig. 7. Example of 45° and 60°inclination of square heat pipe while experiment is in process

The heater is put “on” and the temperature rise is observed at regular intervals till the steady state is achieved. Once the steady state is reached the input power is turned off and by allowing the cooling water to flow through the heat pipe and thermocouple readings are noted from the digital thermocouple indicator. The steady state is defined as

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the variation in temperature for 10min. After taking the readings from the thermocouple indicator the heat pipe is allowed to cool again for 10min and the heat input is increased for further level. Experimental procedure is repeated for different heat inputs (31, 40, 50 and 60W) and for different inclinations of the heat pipe (0°, 30°, 45°, 60°, 75° and 90°) and readings were recorded with distilled water as a base fluid for nanofluid and distilled water as shown in Fig. 7. Various plots are drawn to study the performance of the square heat pipe to optimize the fluid inventory. The different heat inputs are achieved by changing the output voltage from the variac. The angle is kept from the table 3 as length of the rope is calculated.

Fill ratio means the percentage of the evaporator section volume that is filled by the working fluids. The fill ratios used in this experiment are 25%, 50%, 75% and 100% of the evaporator volume for all different quantities of working fluids.

TABLE 3: ANGLE AND LENGTH OF THE ROPE

Sl.No	Angle	Rope Length (Cm)
1	0	100
2	30	98
3	45	95
4	60	90
5	75	82
6	90	71

A. Sample calculations

1) Thermal Resistance (R)

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

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

Where t_e - evaporator temperature
 t_c - condenser temperature
 R - Thermal resistance
 Q - Heat flux

Sample calculation of R at 0° for distilled water
 From the readings: $t_e = 53^{\circ}\text{C}$; $t_c = 30^{\circ}\text{C}$; $Q = 31.08 \text{ W}$
 Thermal resistance of heat pipe

$$R = \frac{53 - 30}{31.08} = 0.97 \left(\frac{^{\circ}\text{C}}{\text{W}} \right)$$

The above procedure is applicable for all the remaining R values at different angles of different heat inputs and different fill ratios of working fluid.

2) Heat transfer coefficient (h)

Heat transfer coefficient of square heat pipe
 Sample calculation of h at 0° for distilled water
 From the readings: $t_e = 53^{\circ}\text{C}$; $t_c = 30^{\circ}\text{C}$; $Q = 31.08 \text{ W}$; $A=0.023 \text{ m}^2$.

$$h_e = \frac{Q}{A * (t_e - t_c)} \text{ (W/m}^2\text{ }^{\circ}\text{C)}$$

$$h = \frac{31.08}{0.023 * (53 - 30)} = 58.75 \left(\frac{\text{W}}{\text{m}^2\text{ }^{\circ}\text{C}} \right)$$

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The above procedure is applicable for all the remaining h values at different angles of different heat inputs and different fill ratios of working fluid.

V. EXPERIMENTAL RESULTS

5.1. 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 thermal resistance vs heat input for different angle of inclination.

It is observed that thermal resistance decreases as the heat increases. 100% fill ratio when assorted with 0.1 g of CuO is lesser than 75% fill ratio of distilled water and 25% of fill ratio assorted with 0.2g of CuO.

For angles 0°, 30°, 45°, 60°, 75° the thermal resistance is less for 100% of fill ratio assorted with CuO compared to 25% fill ratio assorted with 0.2 g of CuO and 75% fill ratio of distilled water.

For angle 90° 75% fill ratio assorted with 0.4g of CuO is lesser than 75% fill ratio of distilled water and 100% fill ratio assorted with 0.1g of CuO. The following are the graphs between thermal resistance and heat input for different angles which shows after the experimental readings are noted and calculated.

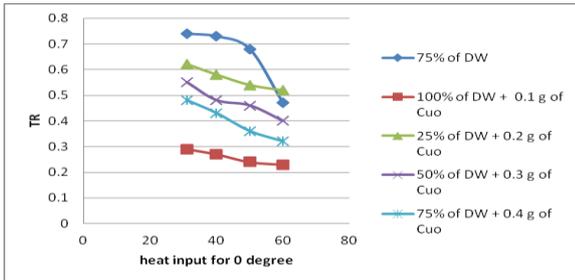


Fig. 9 thermal resistance vs heat input for 0degree inclination

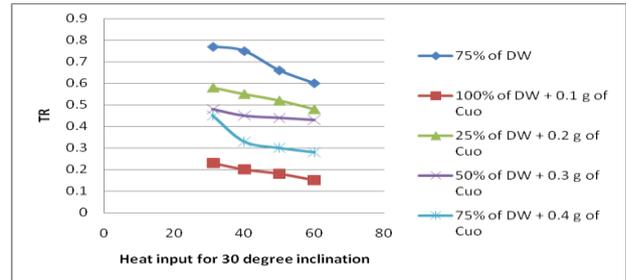


Fig. 10 thermal resistance vs heat input for 30degree inclination

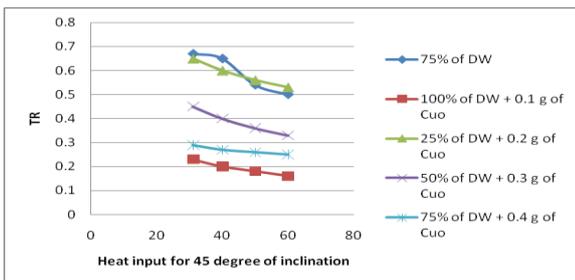


Fig. 11 thermal resistance vs heat input for 45degree inclination

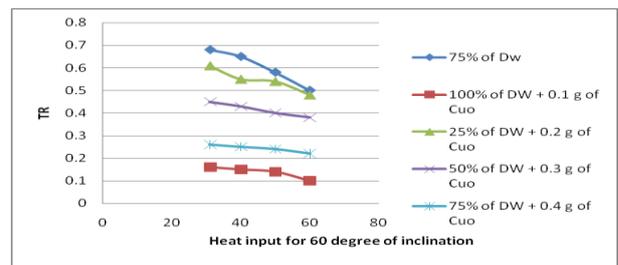


Fig. 12 thermal resistance vs heat input for 60degree inclination

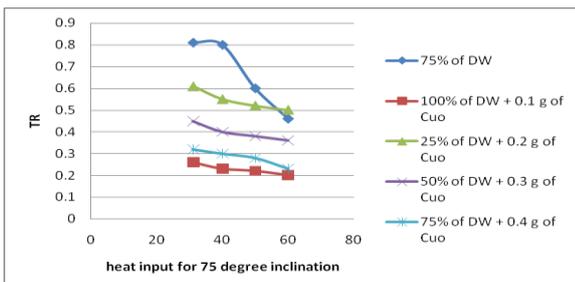


Fig. 13 thermal resistance vs heat input for 75degree inclination

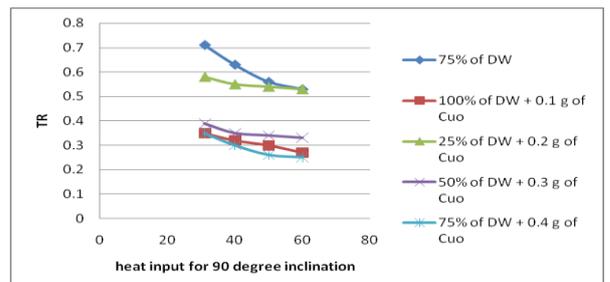


Fig. 14 thermal resistance vs heat input for 90degree inclination

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5.2. Heat transfer coefficient (h)

The readings are noted for square heat pipe and graphs are plotted for heat transfer coefficient (W/m^2) vs heat input. From the graphs it is observed that heat transfer coefficient increases as the heat input increases. Heat transfer coefficient for 100% fill ratio is higher when distilled water is assorted with CuO compared to 75% of distilled water. It is also noted that 100% fill ratio assorted with 0.1g of CuO is higher than 25% fill ratio assorted with 0.2g of CuO.

For angles 0° , 30° , 45° , 60° , 75° , 100% fill ratio with 0.1 g of CuO is higher than 25% fill ratio with 0.2g of CuO. For angle 90° 75% fill ratio with 0.4g of CuO is higher than 25% fill ratio with 0.2g of CuO. The following graphs are plotted between overall heat transfer coefficient and heat input for different angle of inclination.

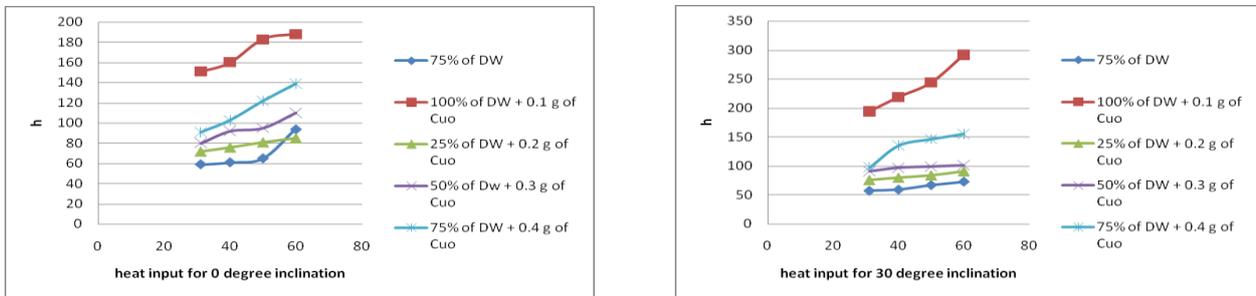


Fig. 15 heat transfer coefficient vs heat input for 0 and 30 degree inclination

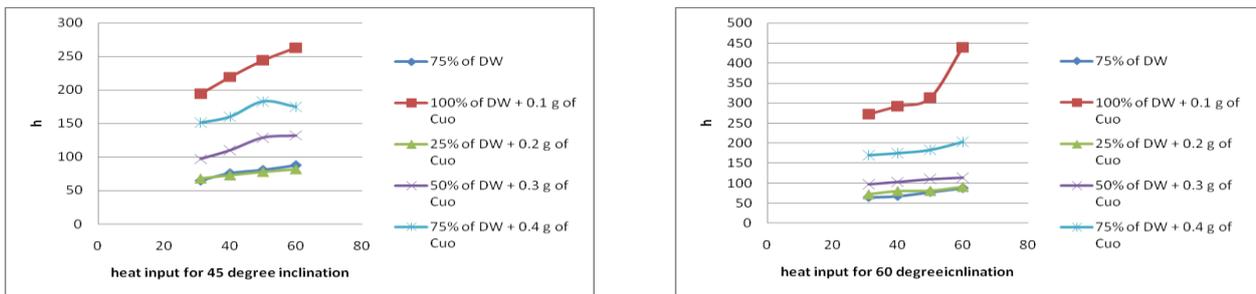


Fig. 16 heat transfer coefficient vs heat input for 0 and 30 degree inclination

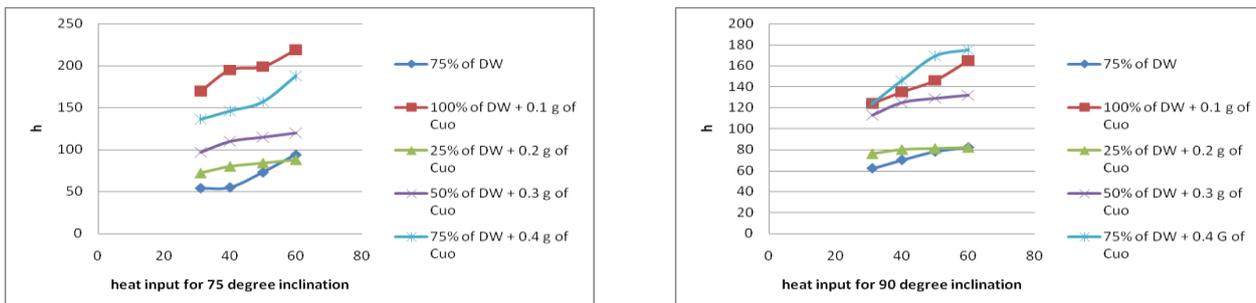


Fig. 17 heat transfer coefficient vs heat input for 0 and 30 degree inclination

VI. CONCLUSION

A square heat pipe of 150W capacity has been developed, fabricated and tested. Different fill ratios used are 25%, 50%, 75%, 100% with different heat inputs like 30W, 40W, 50W, 60W. It is observed that steady state increases with increased heat inputs. From the results it is known that

- The thermal resistance of square heat pipe decreases with increase in heat pipe, in the range of 100% fill ratio assorted with 0.1g of CuO as working fluid the thermal resistance is lesser than 25% fill ratio assorted with 0.2g of CuO.

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- The thermal resistance of water is higher than CuO as a working fluid at different heat inputs and different fill ratios.
- The over all heat transfer coefficient increases when the heat input increases. Heat transfer coefficient for 100% fill ratio is higher when distilled water is assorted with CuO compared to 25% fill ratio.
- It is also noted that heat transfer coefficient is higher for CuO compared to distilled water for different fill ratios and different heat inputs.
- With distilled water as a working fluid at 75% fill ratio has least decrease in thermal resistance and least increase in heat transfer coefficient as heat input increases.
- With CuO as a working fluid 100% fill ratio has higher decrease in thermal resistance and higher increase in heat transfer coefficient as heat input increases.
- With increase in fill ratio thermal resistance and heat transfer coefficient is better than lower fill ratios but when the amount of water is added as a base for CuO the greater quantity gives better thermal resistance and heat transfer coefficient.

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