International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 07, July-2015

Comparison of CuO Thermal Analysis with the Distilled Water in a Dual Diameter Copper Heat Pipe

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***Abstract*— In this paper, Dual diameter copper pipe with a copper screen mesh wick is fabricated to compare the thermal analysis of CuO nanofluid with the distilled water.This heat pipe is brazed with two different diameter copper pipes. A large pipe is used for evaporator section and a small pipe is used for adiabatic and condenser sections. Both the evaporator and adiabatic sections are insulated to avoid the heat losses. CuO nanofluid in three different amounts (high, medium and low) and the distilled water are treated as four working fluids. Each working fluid is individually pulled into the heat pipe by vacuum process. Throughout the angular positions of heat pipe, Heat fluxes are applied from 1727 to 4579 (W/m^2) to the evaporator. Water is circulated amid of an acrylic pipe in the condenser section. Results revealed that the heat transfer coefficients are high for medium amount CuO nanofluid at 0^0,30^0,45^0,75^0 and 90^0, low for distilled water at all angles except at 60^0 and also low for low amount nanofluid at 60^0,75^0(both distilled water and low amount nanofluid have some common h_e values at 75^0).Thermal Resistances are low for medium amount CuO nanofluid at all angles and high for distilled water at 0^0&30^0, for low amount nanofluid at 45^0,60^0,75^0 and 90^0.**

Keywords-Dualdiametercopper Pipe; fabrication;experimentation; thermal analysis

1.INTRODUCTION

Heat pipes are referred to as the "superconductors" of heat due to their quick transfer capability with minimal heat loss. Heat pipe combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces. The concept of the modern heat pipe was first put forth by **R. S. Gaugler** of General Motors Inc. in 1944. He patented a lightweight, heat transfer instrument which was supposedly applied to a refrigeration system. He added the idea of using a wick to make the inner fluid return back to the evaporator, instead of gravity. It resurfaced only during 1962 when **G. M. Grover** and his co-workers from the Los Alamos Scientific Laboratory created prototypes on the design and coined the name "heat pipe". This pipe is used to compare the CuO nanofluid thermal performance with the distilled water. This project was carried out in GPREC from 26-4-2015 to 6-7-2015.

2. HEAT PIPE TECHNOLOGY

Heat pipes employ ***evaporative cooling*** to transfer thermal energy from one point to another by the ***evaporation*** and ***condensation*** of a working fluid. Heat pipes rely on a temperature difference between the ends of the pipe and cannot lower temperatures at either end beyond the ambient temperature (hence they tend to equalize the temperature within the pipe).
When the evaporator section gets heated up externally then the working fluid inside the section absorbs latent heat of vaporization and turns from liquid phase to vapor phase. The vapor pressure of the evaporator section is higher than the equilibrium vapor pressure of the condenser and this pressure difference drives the rapid mass transfer from high pressure evaporator section to low pressure condenser section and starts condensing where the excess vapor releases its latent heat, turns to liquid phase which attains the gravity.

The condensed working fluid then returns to the evaporator section by the capillary action of the copper screen mesh wick section but the speed of the vapor in the heat pipe is limited by the rate of condensation at the cold end.

The ***heat of vaporization*** greatly exceeds the sensible ***heat capacity***. Using water as an example, the energy needed to evaporate one gram of water is 540 times the amount of energy needed to raise the temperature of that same one gram of water by 1 °C. Almost all of that energy is rapidly transferred to the "cold" end when the fluid condenses there, making a very effective heat transfer system with no moving parts.

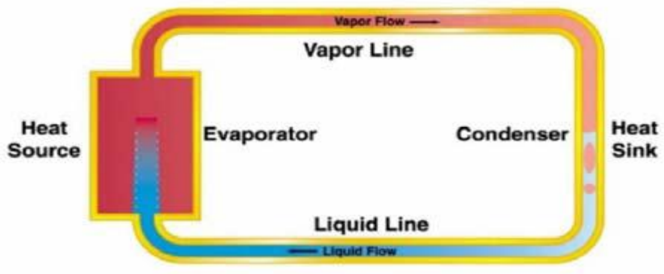

Fig 1: Schematic representation of heat pipe principle

3. BASIC COMPONENTS AND MATERIAL

Consider the four vital components for important mechanism.

- ➢ Copper as the heat pipe material
- ➢ Copper Oxide nanomaterial
- ➢ Copper screen mesh wick
- ➢ Heater

I. Copper as a heat pipe material

Thermacore copper-water heat pipes are specifically designed for applications in which high heat loads or gravity present thermal challenges where the reliability and long life are critical. Using water as the working fluid, the thermacore copper-water heat pipe smoothly moves heat from the heat source to where the heat can be managed more effectively through dissipation to air, liquid or radiated to space. The below figure is the dual diameter Copper Pipe which was used as the Heat Pipe.

Fig 2: Fabricated copper pipe

II. Copper oxide nanomaterial (purity 99%, size =50nm) as a working fluid

It is the higher ***oxide*** of ***copper.*** As a mineral, it is known as ***tenorite***. A copper oxide nanoparticle appears as a brownish-black powder. They can be reduced to metallic copper when exposed to hydrogen or carbon monoxide under high temperature.

Fig 3: Copper oxide nanomaterial

Properties of CuO nanomaterial

- ➢ The chemical composition of copper is 79.87%, oxygen is 20.10%.
- ➢ Melting point is 120 ^{0}C, Boiling point is 2000^{0}C.

Copper oxide nano fluid (other working fluid)

To compare the distilled water (working fluid-1), required amount of CuO nanomaterial was stirred with the 50ml of distilled water in a beaker.

Fig 4: Incite CuO nano Fluid

Table1: Nanofluid Quantities

Sl No	Designation	Quantity
1	High Amount Nano working fluid(working fluid-2)	1000mg of CuO Nanopowder+50ml of distilled water
2	Medium Amount Nano working fluid(working fluid-3)	500mg of CuO Nanopowder+50ml of distilled water
3	Low Amount Nano working fluid(working fluid-4)	200mg of CuO Nanopowder+50ml of distilled water

III. Copper mesh wick

To return the condensed liquid to the evaporator, Copper mesh wick with 25 holes (horizontally)×26 (vertically),nearly 650 holes per inch, used as the screen mesh wick for capillary force.

Fig 5: Copper screen mesh wick

IV. Heater

This heater was prepared by mild steel galvanized sheet. The both ends of a heater were prepared by the brass metal. Inside material was made up of Mica, a filament was used. It withstood up to 230V and 16A. 3/20 wires were used for electricity conduction. It held the evaporator section with the help of screw and nut. The two wires were connected to ammeter, voltmeter and a small Auto-Transformer. Three electric devices were regulated to

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conduct the required electric power, this electric power was converted to heat (for the evaporator section) by the heater.

Heater Principle

Electric heating is any process in which ***electrical energy*** is converted to ***heat***. The ***heating element*** inside every electric heater is an electrical ***resistor*** and works on the principle of ***Joule heating***. An ***electric current*** passing through a resistor will convert that electrical energy into heat energy.

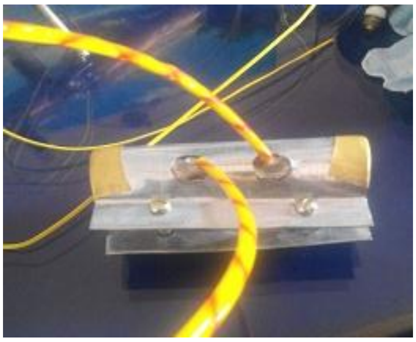


Fig 6: Heater

4. ASSEMBLY

Primarily, a large diameter copper pipe was taken for the evaporator section, which has the capacity to bear the high heat. A small diameter copper pipe was taken for both adiabatic& condenser section. Through the brazing process, both the large& the small copper pipes were hitched .By this configuration the evaporated liquid passed through the nozzle shape entrance of the adiabatic section with the high velocity. This technique reduced the evaporator wall temperature but increased the evaporator working fluid temperature. Then the vapor reached the condenser faster and improved the heat transfer performance of the heat pipe.

Table 2: Dimensions of the three sections

Sl No	Section	Outer diameter (mm)	Inner diameter (mm)	Length (mm)	Area (mm^2)
1	Evaporator	28	25	100	8800
2	Adiabatic	22	19	100	5971
3	Condenser	22	19	100	5971

I. Insertion of copper mesh wick

A copper mesh wick with 100holes per inch was rolled and inserted into the copper pipe. A closed contact between the mesh and the copper inner wall was guaranteed by the internal tension of the mesh.

Fig 7: Copper screen mesh wick

II. Vacuum the copper pipe

Vacuum itself explains the meaning that a region of space which contains no matter. If any unwanted condensing gases leftover in a copper pipe during the experimental work, the bubbles may diminish the effectiveness of the heat pipe. To avoid this effect, the vacuum should be applied to the copper pipe. For the vacuum purpose, a hole of 8mm was drilled and a small screw was fastened to the adiabatic section. To these screw, a small copper pipe was connected by the brazing process.

As seen in followed images, a yellow colored pipe from the compressor which created the vacuum (removed each and every minute particle from the copper pipe), was connected to the blue colored pipe of a pressure gauge which measured the pressure given to the copper pipe. Then the blue colored pressure pipe was connected to the copper pipe.

Procedure

Subsequently, when the pressure attained the negative value then the Vacuum emerged. After the compressor created the vacuum in the copper pipe through the yellow pipe, closed the yellow pipe valve and removed it from the compressor. Atlast, opened the pressure gauge red cap valve when the CuO nanofluid bottle was fitted to it. Due to the vacuum, the suction created pulled off the nanofluid completely into the copper pipe.

III. Hitch the Thermocouples

Very tiny holes were drilled on the heat pipe where equal dimensions were distributed on a copper pipe wall for thermocouples insertion. To overcome the leakage problem, thermocouple was inserted initially into the hole screw, after that a log was connected to the end of an each thermocouple which acts as an earthen material for good electrical conduction and helped to sense the temperature.

A K-type thermocouple was inserted into an each section of a copper pipe to measure the inside working fluid vapor temperature. M-Seal semisolid material sealed the thermocouple screw head to avoid other leakages. Totally, two thermocouples were inserted at the evaporator section, two at the condenser section and two at the adiabatic section. The wall temperature distributions along the circumference direction were quite uniform because the mesh structure could make the liquid film uniformly filled into the mesh of the inclined heat pipe.

IV. Acrylic pipe connection

Then the copper pipe was made dummy to avoid leakages. An acrylic pipe with an outer diameter 38mm, an inner diameter 35mm, was held the copper pipe of a condenser section externally. Water was circulated through the gap between the condenser wall and the acrylic pipe. Both input& output brass opening screws with 5mm internal diameter were connected to an acrylic pipe. For these brass screws, two pipes were fitted. One pipe was submerged into the water tub for condensing the copper pipe and the other pipe for circulated water collection.

The evaporator section of a heat pipe was heated by circumferential heater which held the evaporator section with the help of screws and nuts. Before the copper heat pipe was vacuumed. Insulation was provided by wounding the asbestos rope to both adiabatic& evaporator sections. The heat loss from the evaporator & adiabatic sections were negligible. At last, Electrical Connections were given to ammeter, voltmeter, Digital indicator thermocouple temperature reader box and the auto transformer.

Fig 8: Dual diameter copper pipe

Above pictorial representation proclaimed the copper pipe placed in an angle which was connected to all the components.

EXPERIMENTAL ALGORITHM

Let us have the brief elucidation about the distilled water experimental algorithm. Vacuum the copper pipe with the help of a compressor and filled the 50% working fluid to the entire copper pipe volume. Checked the evaporator section, condenser section& small vacuum copper pipe (connected to the adiabatic section) were insulated without gaps. With the help of nylon rope, fixed the copper pipe to the stand in a required angle. Scrutinized the electrical wires were connected correctly to the ammeter, voltmeter& an auto transformer. Examined the six thermocouples were connected to the Digital indicator thermocouple temperature reader box. Audited the constant flow rate water was circulated through the gap between the copper pipe & an acrylic pipe.

Switched on the power, regulated the ammeter& voltmeter for required heat input (e.g. 15.2 VA) & awaited for 20minutes for vapor formation. After 20minutes, noted the evaporator, adiabatic& condenser internal working fluid vapor & external surface wall temperature. Switched off the power. For the initial state, cooled the copper pipe with the water and a fan for 20minutes for further experimental purpose. And the cycle was repeated for next heat inputs 20.7VA, 25VA, 30.24VA, 35.99VA, 40.3VA at a constant angle. Repeated the heat pipe experimental work for high, medium and low amount nanofluids in different angles 0^0 ,30^0,45^0,60^0,75^0 and 90^0.

5. CALCULATIONS

Heat Pipe Inclination Angles

Needed rope length to fix the heat pipe in required angle,

Let the heat pipe fixed in 30^0

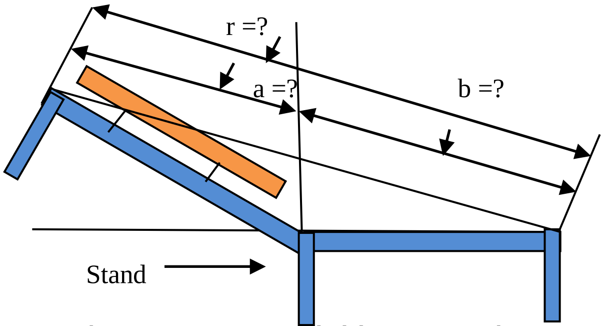
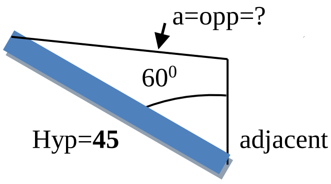


Fig 9: Schematic representation of dual diameter copper heat pipe in 30^0

For this triangle,



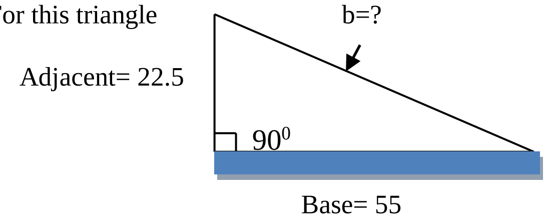
$$\text{Sin}60^0 = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$a = \text{Opposite} = \frac{\sqrt{3}}{2} \times 45 = \mathbf{38.97cm}$$

$$\text{Cos}60^0 = \frac{adjacent}{45}$$

Adjacent=22.5

For this triangle



According to the Pythagoras theorem

$$b = \sqrt{adjacent^2 + base^2}$$

$$= \sqrt{22.5^2 + 55^2} = \mathbf{59.42cm}$$

Rope length (r_L) = a +b

=38.97+59.42= **98.4cm**

Table 3: Rope length for different angles

Sl No	Angles	Rope length (cm)
1	0^0	100
2	30^0	98.4
3	45^0	95.4
4	60^0	90
5	75^0	81.75
6	90^0	71

Evaporator thermal resistance (R_e)

The evaporator thermal resistance was calculated to find out the amount of heat resisted or opposed by the evaporator wall& the working fluid. It is defined as

$$\mathbf{Re} = \frac{\mathrm{Te,w - Te,v}(^\circ C)}{Q(W)} \longrightarrow \quad (1)$$

Where Te,w is the evaporator wall temperature, Te,v is the vapor temperature in the evaporator section and Q is the input power.

Calculating the R_c at 0^0 for the distilled water

From the observation: $T_{e,w}$ =61 ^{0}C , $T_{e,v}$=53 ^{0}C at Q=15.2 W

From equation (1), Re $=\frac{61-53}{15.2}$=**0.53(^{0}C/W)**

This procedure can be applicable to all remaining Re values at different angles for different heat inputs and working fluids.

Condenser thermal resistance (R_C)

The Condenser thermal resistance was calculated to find out the amount of heat resisted or opposed by the Condenser wall& the working fluid. It is defined as

$$\mathbf{R_C} = \frac{\mathrm{Tc,v - Tc,w}(^\circ C)}{Q(W)} \longrightarrow \quad (2)$$

Where Tc,w is the Condenser wall temperature, Tc,v is the vapor temperature in the Condensed section and Q is the input power.

From the observation, $T_{C,W}$=43^{0}C , $T_{C,V}$=44^{0}C at Q=15.2W

From equation (2), Re=$\frac{44-43}{15.2}$=**0.066(^{0}C/W)**

This procedure can be applicable to all remaining R_c values at different angles for different heat inputs and all working fluids.

Total Thermal Resistance (R)

The total thermal resistance of the heat pipe is calculated to find out the amount of heat resisted by the copper pipe i.e heat pipe. It can be defined as:

$$\mathbf{R} = \frac{\mathrm{Te,w - Tc,w}(^\circ C)}{Q(W)} \longrightarrow \quad (3)$$

From above values, R=$\frac{61-43}{15.2}$=**1.2(^{0}C/W)**

This procedure can be applicable to all remaining R values at different angles for different heat inputs.

Heat Transfer Coefficient (h_e)

The resistance to the flow of heat by the material of pipe wall can be expressed as a "***heat transfer coefficient of the pipe wall***". Selecting the heat flux on the pipe inner diameter, and assuming that the pipe wall thickness is small in comparison with the pipe inner diameter, then the heat transfer coefficient for the pipe wall can be calculated as if the wall were not curved.

The heat transfer coefficient at the evaporator section is calculated

$$\mathbf{h_e} = \frac{\textbf{Heat Flux}}{\textbf{Evaporator Temperatures difference}} = \frac{\frac{Q}{A}(\frac{W}{m^2})}{\mathrm{Te,w - Te,v}(^\circ C)} \longrightarrow$$
(3)

Where, Heat Flux= $\frac{Q(\text{Heat Input})}{A(Area)}$

Area of an evaporator section (A) $=2\times \Pi \times r \times l$

(r=$\frac{d}{2}$, where d is the outer diameter of the evaporator section, l= length of an evaporator section)

$$=2\times \frac{22}{7} \times 14 \times 100(\text{from table})$$

Area=>8800mm^2=**0.0088m^2**

When Q=15.2, Heat flux=$\frac{15.2}{0.0088}\frac{(W)}{(m^2)}$ =1727.27$\frac{W}{m^2}$

similarly, calculations were done for all heat fluxes.

$$\mathbf{h_e}=\frac{1727.27}{61-53}=\mathbf{216}\frac{(\frac{W}{m^2})}{(^\circ C)}$$

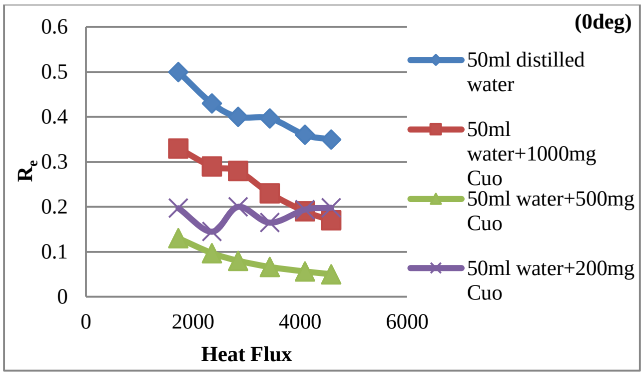
This procedure can be applicable to all remaining he values at different angles for different heat inputs.

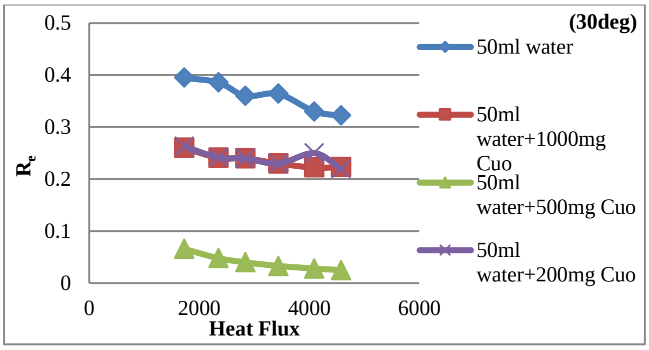
RESULTS AND DISCUSSION

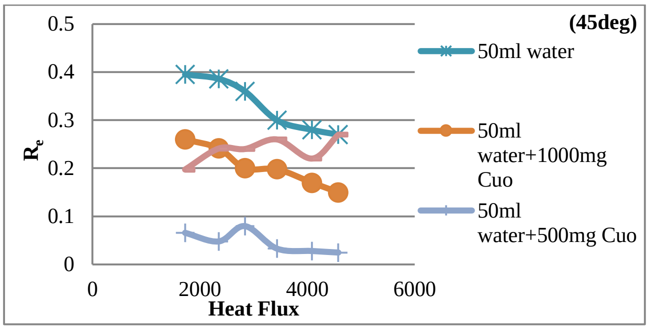
According to the heat transfer principle (heat transfers from high temp to low temp), If $T_{e,w}$ >$T_{e,v}$ then heat transfers from $T_{e,w}$ to $T_{e,v}$. Hence it indicates that the copper pipe wall has a good thermal conductivity.

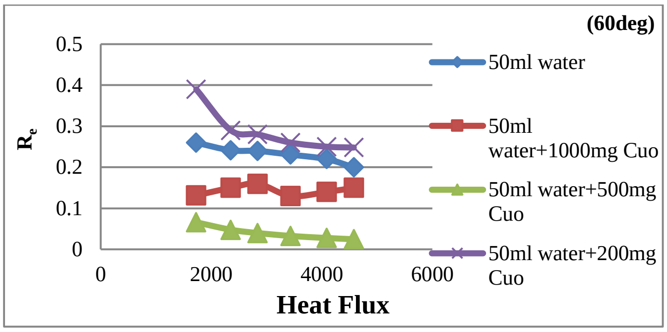
Evaporator Thermal Resistance

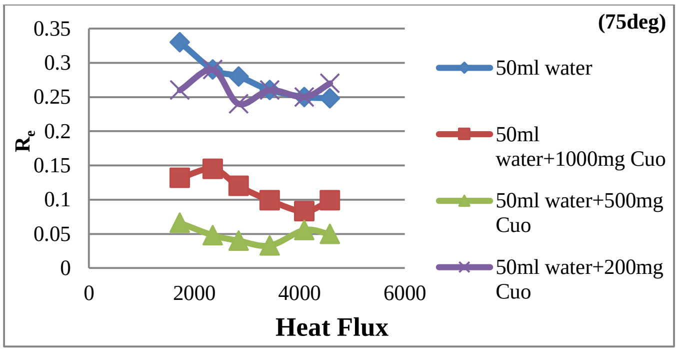
Low R_e divulge that heat transfers from external evaporator wall to internal working fluid.

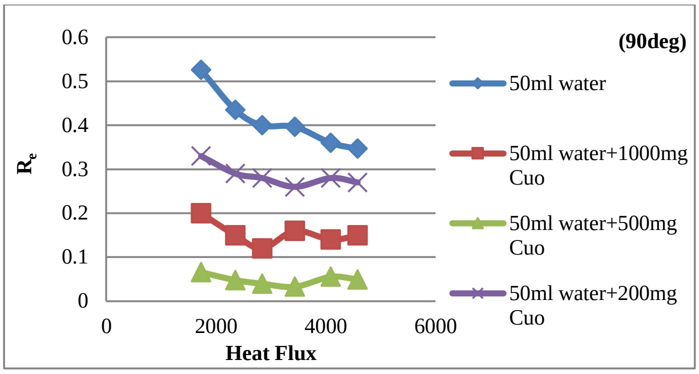










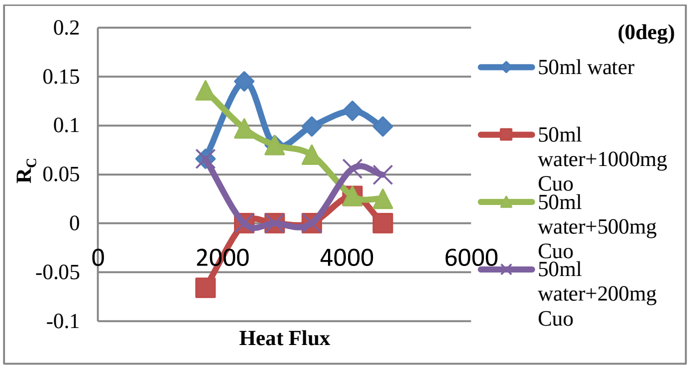


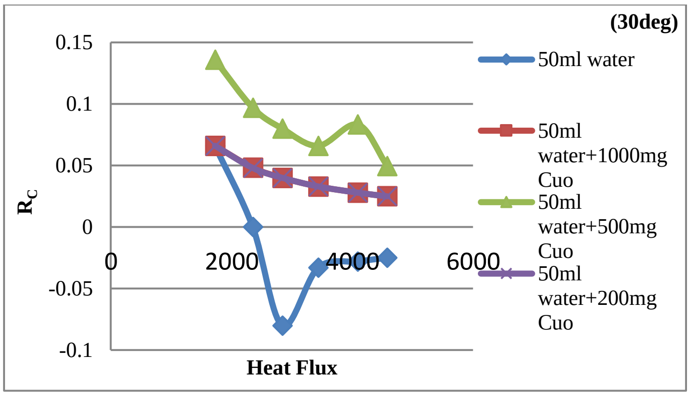
Graph represents that the dual diameter copper pipe has a low evaporator thermal resistances for medium amount nanofluid at all angles and a high evaporator thermal resistances for distilled water at 0^0, 30^0,45^0, 75^0&90^0, for low amount nanofluid at 60^0.

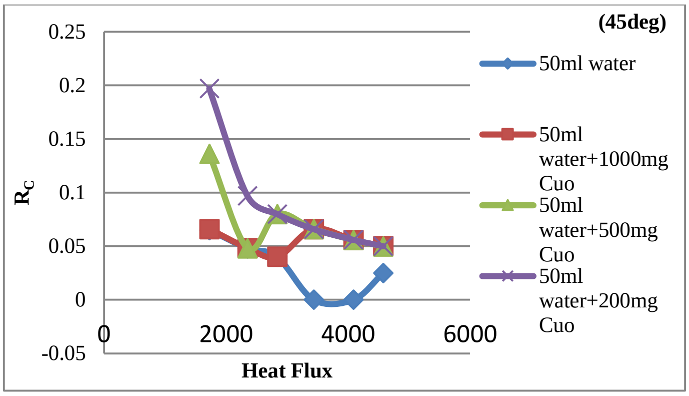
R_e is considered for good heat transfer but sometimes low R_e (when this copper pipe absorbs a high heat that is greater than the copper pipe melting point heat) leads to copper pipe melting.

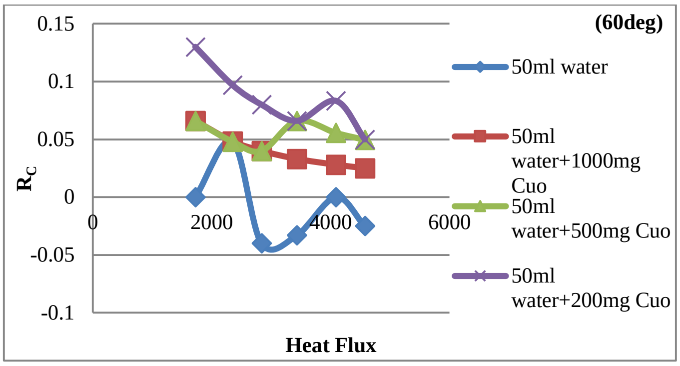
Condenser Thermal Resistance

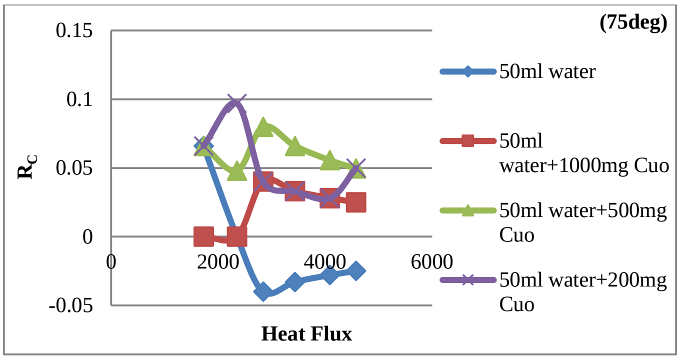
High R_C tells that heat transfers from internal working fluid to external water section that condenses the section.

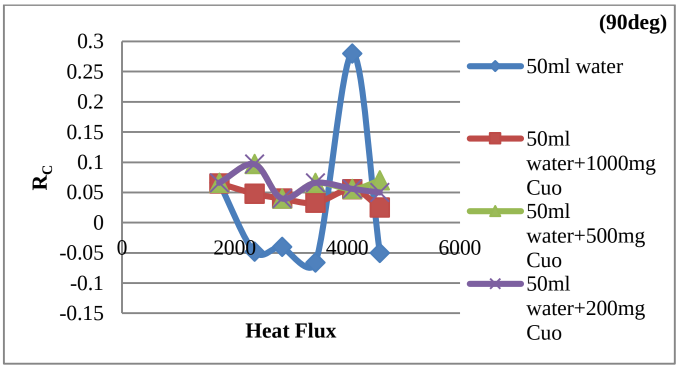












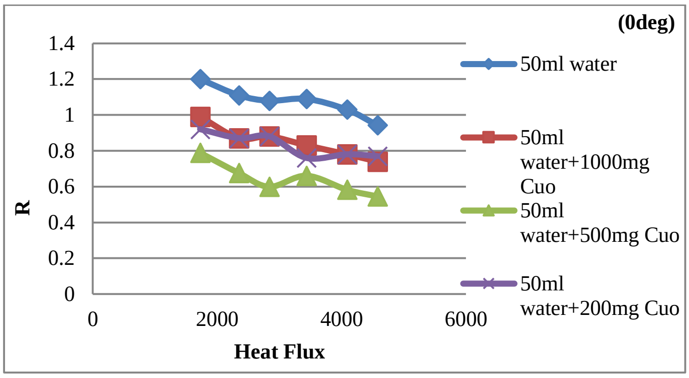
Condenser thermal resistance means condenser section opposes the heat. Graph demonstrates that dual diameter copper pipe has a high condenser thermal resistances for distilled water at 0^0, medium amount nanofluid at 30^0, low amount nanofluid at 45^0& 60^0, low& medium amount nanofluid at 75^0 for high heat flux, low amount nanofluid for low heat flux at 75^0& distilled water at 90^0 and has a low condenser thermal resistances for high amount nanofluid at 0^0, for distilled water at, 30^0,45^0 , 60^0 , 75^0&90^0 .

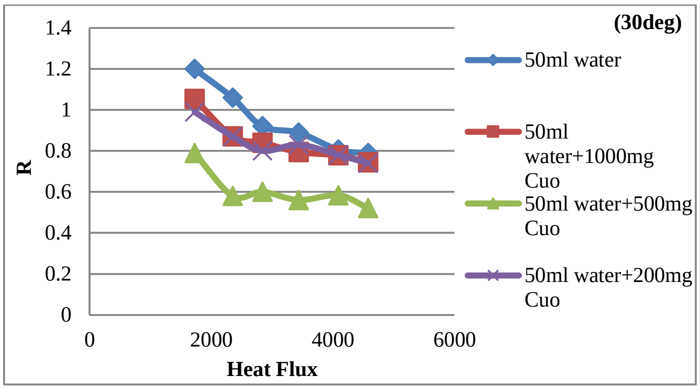
If R_C is more, the amount of condensed liquid is too more. The condensed liquid moved to the evaporator section very quickly due to its more density, gravity.

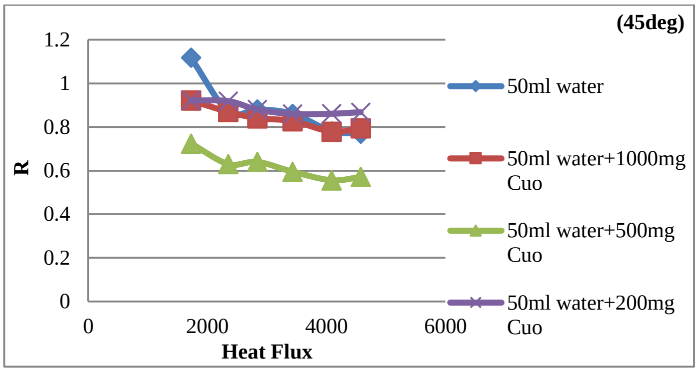
If R_C is less, the heat absorbed by the condenser section is more due to the high thermal conductivity of CuO nanofluid. A high amount of nanomaterial leads to the high heat.

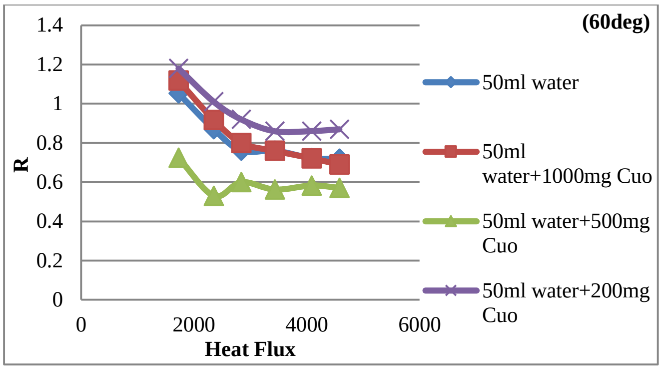
Thermal Resistance

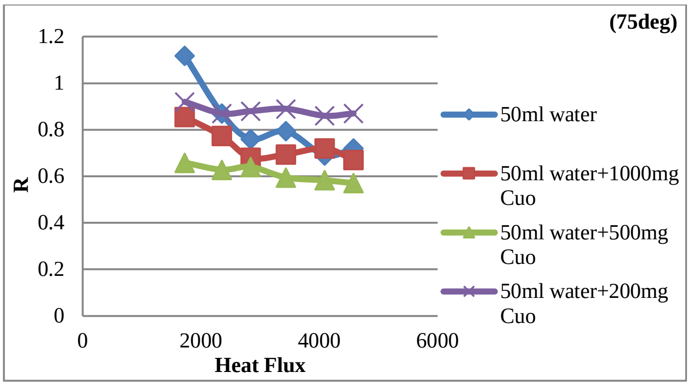
A copper pipe that resists the heat is to be considered as the good thermal resistant. High thermal resistant copper pipe avoids the melting situation.

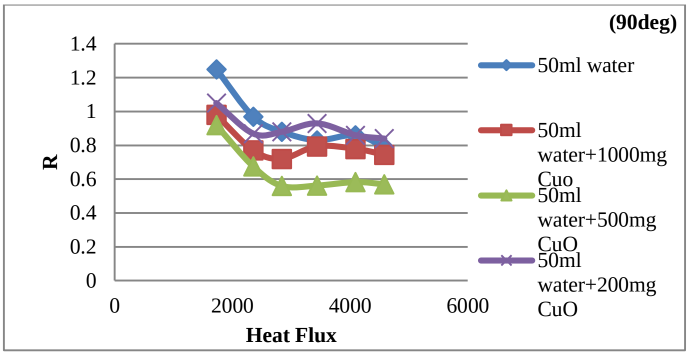










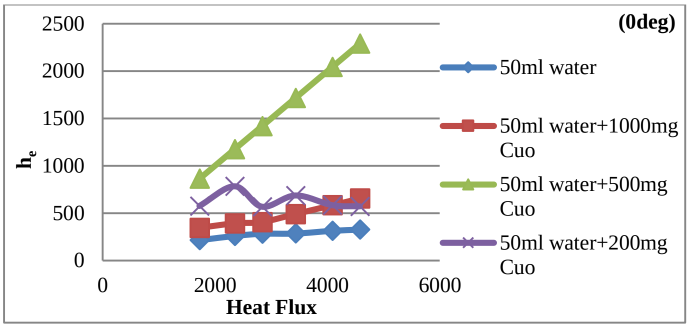


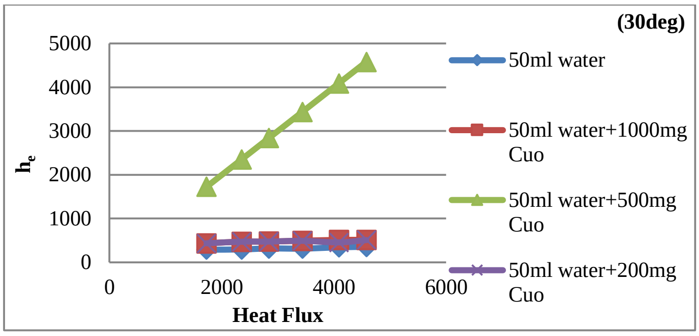
Thermal resistance means opposes the heat. Increasing the heat flux, warms the evaporator section and decreases the thermal resistance. Graph displays that a copper pipe has a low thermal resistance for medium amount nanofluid at all angles, It has a high thermal resistances for distilled water at 0^0& 30^0, for low amount nanofluid at 45^0, 60^0, 75^0 &90^0.

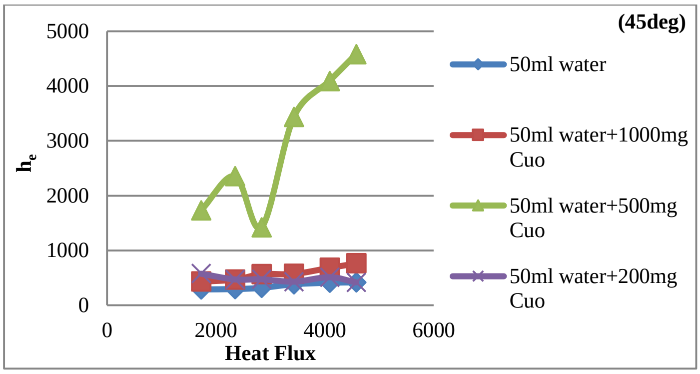
If R is more, the amount of heat absorbed by the copper pipe wall is low. It can be different, based upon the type of working fluid used. If the water is used as the working fluid in copper pipe, heat absorbed by the water is low. If the CuO nanofluid is used as the working fluid, heat absorbed by the nanofluid is more, then R is also more.

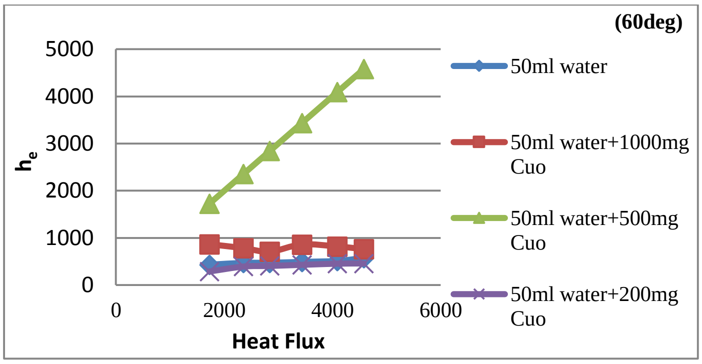
Heat transfer coefficient

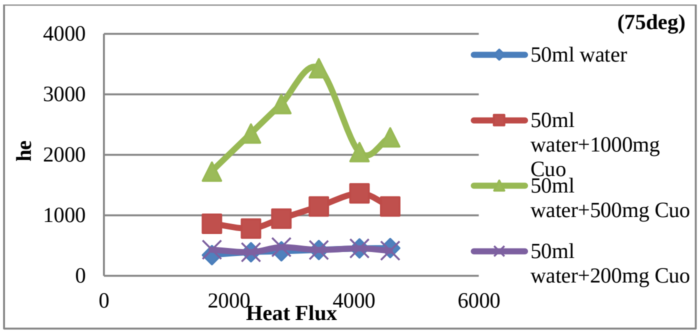
High h_e leads to high heat transfer from high temperature section to low temperature section.

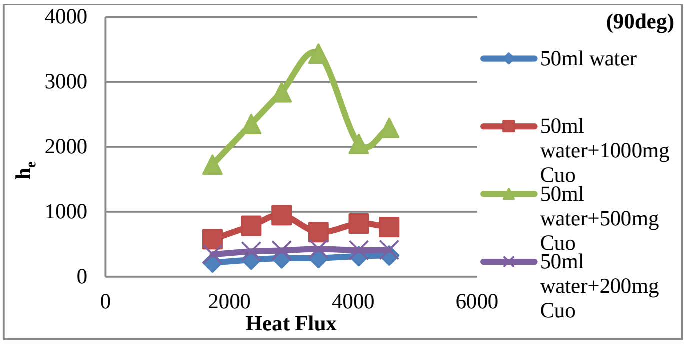












Dual diameter copper pipe has a high heat transfer coefficients (heat transfer performance) when medium amount nanofluid used at 0^0, 30^0, 45^0, 60^0, 75^0&90^0 (all applied) angles and has a low heat transfer coefficients for distilled water at 0^0, 30^0, 45^0, 75^0& 90^0, for low amount nanofluid at 60^0 &75^0 .Both distilled water &low amount nanofluid have some common h_e values at 75^0. Sometimes, due to the dry out occurred in the internal evaporator surface, $\mathbf{h_e}$ decreases with increasing the heat flux.

CONCLUSION

From the experimental work, the heat transfer coefficients are high for medium amount CuO nanofluid at all six angles. Thermal and Evaporator thermal Resistances for medium amount CuO nanofluid are low at all angles. High condenser thermal resistances are obtained for distilled water at 0^0 and low amount nanofluid at 45^0.Increasing the contact angle (setting the evaporator in lower level than the condenser) causes the condensed vapor returns faster to the evaporator section by means of gravity and consequently, lower thermal resistances and higher heat transfer coefficients were obtained. Therefore medium amount nanofluid is the most suitable f or high heat transfer.

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