TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

Effect of Heat Transport Fluid and Influence of Gravity Assistance in Heat Pipe Induced in Concentric-Tube Shell Assisted Heat Exchanger

P.Ramkumar[a*], M.Sivasubramanian[b], P.Rajesh Kanna[c], P.Raveendiran[d], Narayanan Selvapalam[e]

[a] Department of Mechanical Engineering, School of Automotive and Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, 626126, Tamilnadu, India.

[b] Department of Automobile Engineering, School of Automotive and Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, 626126, Tamilnadu, India.

[c] Department of Mechanical Engineering, Al Ghurair University, Dubai, United Arab Emirates.

[d] Department of Mechanical Engineering, Annamalai University, Annamalai Nagar, 608 002, Tamilnadu, India.

[e] Center for Supramolecular Chemistry and Department of Chemistry, International Research Center, Kalasalingam Academy of Research and Education, Krishnankoil, 626126, Tamilnadu, India.

*Corresponding author. Ph: +91 9791298174. E-mail address: rkmailmech@gmail.com

Article Info
Volume 82
Page Number: 1623 - 1638
Publication Issue:
January-February 2020

Abstract

An Experimental investigation is done on the heat pipe with gravity induced in a concentric-tube shell assisted heat exchanger under the influence of heat transport fluid. To augment the heat transfer characteristics of the heat pipe, water and copper oxide with De-Ionized water mixture (CuO/DI) nanofluid at volume concentration of 0.4% are used as heat transport fluids at evaporator section and methanol (CH3OH) as a working fluid. Investigations are carried out with an inclination angles with reference to the heat pipe axis to the horizontal reference as 10º, 30º, 50º and 70º. In this analysis, mass flow rate and temperature of the hot and cold fluids are considered for further study. Hot fluid with a mass flow rate ranges from 40 LPH to 80 LPH, cold fluid with 20 LPH to 40 LPH and the inlet temperatures of hot fluids as 50ºC, 55ºC and 60ºC and cold fluid as 33.5ºC is considered for the investigation. The result reveals that increase in effectiveness is occurs when nanofluid is used as heat transport fluid. It is observed that, inclination angle at 50º, inlet hot fluid temperature 60ºC and mass flow rate 80 LPH, 60% of increase in effectiveness is achieved and ensured the effect of gravity influences on effectiveness.

Keywords: Heat pipe, concentric-tube heat exchanger, Gravity assistance, Nanofluid, Heattransport fluid, Effectiveness.

Nomenclature

A	-	Area of heat transfer (m^2)
C	-	Heat capacity rate (kW/K)
C_p	-	Specific heat of the fluid (kJ/ kg K)
D	-	Diameter (m)
h	-	Heat transfer coefficient (W/m^2K)
m	-	Mass flow rate of fluid (LPH)
N	-	Total number of heat pipe
L	-	Length (mm)
Q	-	Heat transfer rate (W)

Abbreviations

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

CuO/DI water	-	Copper Oxide with De-Ionized Water mixture
GICTSAHPHE	-	Gravity Induced Concentric-Tube Shell Assisted Heat Pipe Heat exchanger
HTF	-	Heat Transport Fluid
LPM	-	Liter Per Minute
LPH	-	Liter Per Hour
LMTD	-	Log Mean Temperature Difference
NTU	-	Number of Transfer Units
WF	-	Working Fluid
Subscripts		
c	-	Cold fluid
h	-	Hot fluid
i	-	Inlet
l	-	Liquid
max	-	maximum
min	-	minimum
o	-	Outlet
v	-	Vapour
Greek Letters		
ΔT	-	Difference in temperature (^{o}C)
k	-	Thermal conductivity (W/m K)
$\in$	-	Effectiveness (%)
ψ	-	Inclination angle (^{o})
λ	-	Evaporation of latent heat (kJ/kg)
ρ	-	Density (kg/ m^3)
μ	-	Viscosity (Ns/m^2)
σ	-	Surface tension of liquid (N/m)
ν	-	Specific heat ratio (-)
γ	-	Nucleation radius (m)

Article History

Article Received: *14 March 2019*
Revised: *27 May 2019*
Accepted: *16 October 2019*
Publication: *07 January 2020*

1 Introduction

The heat transfer enrichment techniques are widely used in several industries and processing plants such as power plants, process industries, refining industries, electronic industries in the required zone. The heat pipe employs the technique in which augment of heat transfer behavior which leads to better results with high-temperature space power system in industries were reported by Ivanovskii *et al.* [1]. The recovery of heat released in laboratories and hospitals were investigated using methanol and heat pipes in three rows, increased the efficiency and effectiveness were reported by Baghban and majideian [2]. Joudi and Witwit [3] designed and compared the performance of gravity induced heat pipes and reformed the heat pipes with a segment at the adiabatic region. This investigation reveals the gravity influence and segments in adiabatic section makes better performance in the results.

The efficiency of the normal heat pipes were compared to a gravity influenced heat pipes. This shows maximum performance and better results while using gravity assistance in heat pipes were reported by Nozu [4]. Azad and Geoola [5] investigated with $\in$-NTU model for gravity-assisted air interacted with air heat-pipe heat exchanger. Investigation shows the higher external thermal resistance in the heat pipe with minimum thermal performance on the system. Azad *et al.* [6] designed a gravity influenced, water interact with air heat pipe heat exchanger and tested analytically. The investigation reveals, overall effectiveness increases while increasing the Reynolds number. Tan J. O and Liu C. Y [7] investigated the thermal characteristics on the heat

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

pipe with heat exchanger with ∈-NTU method and compared it with the results obtained by the LMTD method investigation. The Study concluded that ∈-NTU method has good results.

Alicetin Gurses and Cannistrano [8] reported experimentally and analytically about the gravitational effect on the efficiency of water filled heat pipes. It was predicted that the performance of heat pipe, robustly depends on the gravitational effect and inlet temperature. They disclosed that an important feature affecting the heat transfer rate was capillary pumping limit up to 45º and effective operating range was around 45º to 90º of inclination angle.

Savino *et al.* [9] investigated to compare various heat pipes, with a composite wicked or wickless, with pure water and water/alcohol binary mixture under various gravitational conditions. They reported that the heat pipes with binary mixtures performs better than the heat pipes with pure water. The experimental investigation for a different prototype of flat heat pipes working against gravity assistance, compared the numerical with an experimental study depicts the better performance in the investigation. In which thermal resistance was minimum and coefficient of performance have twice the value than theoretical prediction were reported by Esarte and Domiguez [10].

Shabgard *et al.* [11] introduced a thermal network model to investigate the thermal behaviour in a high temperature latent heat thermal energy storage system. The analysis is made in solar thermal electricity generation by inserting several heat pipes between a heat carrying fluid and a phase change material. They demonstrated that by introducing multiple heat pipes improves the efficiency, which is quantified by dimensionless heat pipe's efficiency.

Kempers *et al.* [12] performed an experimentation to state the numbers of mesh layer and quantity of working fluid in the thermal behaviour of copper-water heat pipes with screen mesh wicks. Investigation reveals that the decrease in the thermal resistance was observed and improved the heat transfer achievement through the increment in the numbers of mesh layer of a wick. Said and Akash [13] had experimentally studied heat pipes, at various angles with 30º, 60º and 90º using water as a working fluid. One heat pipe contains a wicked while the other has wickless. Investigation concluded that the wicked heat pipe has higher overall heat transfer coefficient than wickless. The efficiency of a wicked heat pipe has significantly improved, while the heat pipe in vertical position (90º with reference to horizontal). Rahimi *et al.* [14] augmented the heat transfer characteristics of a condenser region and evaporator region of a height one-meter clogged two-phase thermosyphon with water. Their results showed that in a plain pipe there is an increment in heat transfer performance and decrement in the thermal resistance. Shimura *et al.* [15] analysed the thermal resistance with various working fluids at different tilt angles with gravity assistance and found that thermal behaviour of heat-pipe depends on gravitational influence for all types of working fluids.

Lodhi and Gupta [16] analysed the performance of copper heat pipe using CuO/DI water with three different volume concentrations as 1gram/Liter, 5 gram/Liter and 10 gram/Liter. The experimental result reveals that the thermal conductivity and heat transfer rate increment by 50 % and 1.75 % respectively by using CuO/DI water as working fluid. Wongcharce and Elamsa-ard [17] analysed the friction factor and thermal behaviour of CuO/DI water nanofluid experimentally through a cylindrical tube with improved twisted tape in a different axis, varying nanofluid volume concentration from 0.3 to 0.7 %. Investigation reveals that the highest thermal efficiency has been obtained at 0.7 %.

Hasanuzzaman *et al.* [18] observed the efficiency of the counter flow heat exchanger using nanofluids such as CuO-water, Al_2O_3-water and T_iO_2-water of 2 % nanoparticle concentration and compared the thermal performance using water as working fluid. Investigation shows that there is increment of 81% for convective heat transfer coefficient and 23 % of overall heat transfer coefficient of CuO-water than water this shows higher effective than other nanofluids. Shafai *et al.* [19] analysed the thermal performance on heat pipes with a different nanofluids such as Al_2O_3, CuO and T_iO_2 in water as working fluid for various heat inputs and reported the enhancement of thermal performance by using nanofluids in heat pipes.

Durga Bastakoti *et al.* [20] investigated to analyse the efficiency of Pulsating Heat Pipe with Methanol, Ethanol, Cetyltrimethyl ammonium chloride and related with De-ionized water with various concentrations and fill ratios. The inferior thermal resistance with De-ionized water was evident with 50% fill ratio. In which viscosity increases as the concentration increase this hinders the flow within the capillary.

In the works of literature, it is observed that researchers have investigated with limited geometrical and working constraints of heat pipe heat exchanger. The constraints consider for the investigation such as working fluids, fill ratios, heat transport fluids, and geometrical influence in heat pipe heat exchanger with construction parameters. To overcome the above constraints in the present investigation the heat pipe is designed with Gravity assistance and induced in a concentric-tube heat exchanger. The further investigation is carried out with various inclination angles along with heat transport fluids and working fluid. The physical input parameters of the heat transport fluids are measured with different mass flow rates and temperatures input at both evaporator and condenser regions.

2 Experimental Test Rig and Procedure

2.1 Experimental Fabricated Test Rig

To analyse the heat transfer behavior of a GICTSAHPHE, a setup is fabricated and shown in Figure 1 and the physical parameters are given in Table 1. In this work, GICTSAHPHE is fabricated with copper as a heat pipe and galvanized iron as shell material for heat exchanger.

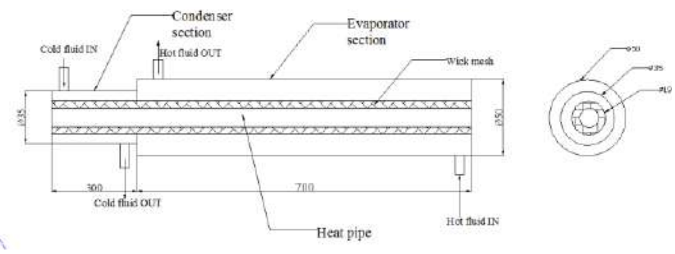

Figure 1. Schematic diagram of a shell assisted Heat-pipe Heat exchanger

Two fluid baths are fabricated for hot and cold fluid regions. In which hot fluid bath has a capacity of 5 liters, contains one coiled immersion electric heater with 2 KW capacity and a temperature controller to monitor and regulate the hot fluid temperature. Cold fluid bath has a capacity of 5 liters and one thermocouple to measure the temperature of cold fluid. Two rotameters with a capacity of 3 LPM are used to measure and control the flow rates of both hot and cold fluid regions. At the evaporator and condenser sections, two thermocouples at each section are used to measure the entry and exit of hot and cold fluid. Two thermocouples were measure the surface temperature of evaporator and condenser section to observe the heat interaction in the system with the surrounding environmental temperature condition.

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

Table 1. Parameters of a GICTSAHPHE

Parameters	Experimental Test Rig
Material of Heat pipe	Copper
Evaporator and Condenser shell Material	Galvanized Iron
Wick material	Stainless steel
Heat pipe working fluid	Methanol
Heat transport fluid	Water and CuO/DI water
GICTSAHPHE Total length (L) and diameter (D_o)	1000 and 50 mm
Heat pipe outer diameter (D_o) and an inner diameter (D_i)	19 and 17 mm
Heat pipe length (L)	1000 mm
Condenser diameter of Heat pipe (D_o)	35 mm
Condenser Length of Heat pipe (L)	300 mm
Evaporator Length of Heat pipe (L)	700 mm
Number of wires/unit length of mesh	2000 m^{-1}
Wick permeability (K)	1.3 x 10^{-9} m^2
Wick porosity (φ)	0.7
Mesh size	50 holes/inch

2.2 Experimental Procedure

In the GICTSAHPHE, a heat pipe is induced inside the concentric-tube heat exchanger with gravity assistance is shown in Figure 2.

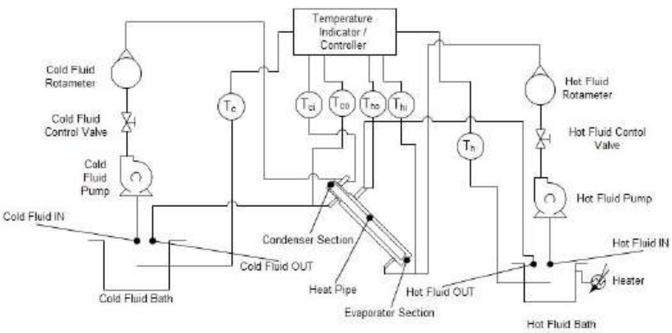

Figure 2. Schematic diagram of an Experimental setup of GICTSAHPHE

Heat pipe is filled with methanol as working fluid after the vacuuming process to remove the presence unwanted gases. Methanol is filled at a Fill ratio of 100% it is 15ml, its thermo-physical properties are given in Table 2. At initial condition heat transport fluid is chosen as water and further, it is carried out to CuO/DI water (0.4 % volume concentration) Nanofluid.

Table 2. Thermo physical properties of methanol

Properties	Range
Boiling point	64°C
Evaporation of latent heat (λ)	1055 kJ/kg
Density of liquid (ρ_l)	746.2 kg/m^3
Density of vapour (ρ_v)	1.47 kg/ m^3
Thermal conductivity of liquid (k_l)	0.201 W/m K
Viscosity of liquid (μ_l)	0.314 x 10^{-3} Ns/m^2
Surface tension of liquid (σ)	1.85 x 10^{-2} N/m
Molecular weight (M)	32 kg/kg-mol
Specific heat ratio (ν_v)	1.33
Nucleation radius (γ_n)	2.54 x 10^{-7} m

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

At initial condition, GICTSAHPHE is fixed at 10º inclined angle and the heat pipe is filled with methanol as WF and HTF as water. Hot fluid mass flow rate are fixed as 40 LPH and inlet temperature as 50 ºC. The cold fluid mass flow rate as 20 LPH and inlet temperature as 33.5 ºC is the ambient temperature. At the evaporator region of a concentric tube heat exchanger, hot fluid transfers the heat to the methanol in the heat pipe. Thus WF absorbs the heat and latent heat of phase change is observed. This in-turn converts to vapour phase and starts moving towards the condenser zone of the heat pipe. In the condenser region, cold fluid in the outer circumference of heat pipe observes the heat from the vapour working fluid and sensible heat of phase change occurs at the condenser region. Thus inlet cold fluid absorbs heat and converts to warm fluid at condenser region is measured using thermocouple at inlet and outlet. Similarly working fluid in vapour phase is converts to liquid phase and moves towards the evaporator region through wick, due to the capillary action of heat pipe. The gravity assistance also induce the working fluid movement from condenser to evaporator region along the heat pipe. Further investigation is carried out with various inclination angles as 30º, 50º, and 70º, hot and cold regions mass flow rates as 60 LPH, 80 LPH and 30 LPH, 40 LPH. Temperatures at an inlet of hot and cold regions are 55 ºC, 60 ºC and 33.5 ºC. The above conditions are repeated for CuO/DI water (0.4 % volume concentration) as HTF and investigated. The whole length of a shell is insulated using 10 mm thickness of Styrofoam material to minimize the heat interaction to the surrounding environmental conditions, surface temperature is observed between heat pipe and ambient condition as 0.2 ºC at 60 ºC of temperature input of hot fluid, it is considered as negligible amount of heat dissipation for this investigation. In this investigations the Heat transfer rate, Nusselt number, Friction factor, Heat transfer coefficient, Reynold's number and Effectiveness are calculated using above stated parameters.

2.3 Importance of Gravity Influence in GICTSAHPHE

- The influence of gravitational effect along the heat pipe shows the faster movement of methanol from the condenser to the evaporator regions.
- Aggrandize the rate of condensate (Methanol) returning from the condenser section.
- An Inclination of GICTSAHPHE produces gravitational effect it develops inferior surface tension in the methanol, produces an increment in the rate of heat transfer.
- GICTSAHPHE has a capillary structure to prevent the liquid methanol against the shear stress exerted by the counter-flowing vapour and this can augment the circumferential scattering of methanol in the evaporator region.

2.4 Preparation of Nanofluid

Copper oxide nanofluids with De-Ionized water mixture (CuO/DI) is used as heat transport fluid in this investigation, which shows maximum specific surface area which leads to higher heat conduction along the fluids. The law of mixture formula is used for the preparation of nanofluids from the CuO nanoparticles and photographic view of CuO nanoparticles are shown in Figure 3. A sensitive digital weighing balance of 0.1 milligram resolution measures the quantity of nanoparticles. The quantity of the nanoparticles required for the preparation of one hundred milliliter nanofluid of a volume concentration, using De-Ionized water as base fluid, is calculated by the equations (14) and (15). The preparation of CuO nanoparticles in 100ml DI water base fluid it requires 2.4422 grams of CuO nanoparticles. The Nanofluid is prepared by magnetic stirring process and by ultrasonic vibration for about five hours. Thus CuO nanofluids of 3 liters are prepared. The observation is made in the time interval about five

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

hours with 70°C no particle settlement is observed. The photographic view of Copper oxide nanofluids with De-Ionized water nanofluid is as shown in Figure 3 a.

Figure 3 . Photographic view of CuO nano particles

Figure 3 a. Photographic view of CuO/DI water (0.4 % concentration) Nanofluid

In this investigation, CuO nanoparticle is procured from an Alfa Aesar a Johnson Matthey Company (AS#1317-38-0) and its thermo-physical properties are given in Table 3.

Table 3. The Thermo-physical properties of Copper oxide nanofluids with De-Ionized water mixture Nano fluid

Properties	Values
Colour and appearance of Nano particles	Brown Powder
Particle size of Nano particles	30-50 (nm)
Thermal Conductivity	18 (W/m K)
Purity	99.0 (%)
Density of nano fluid	6510 (kg/m^3)
Specific Heat of nano fluid	540 (J/kg K)

2.4 Data Reduction

In this experimental investigation heat transfer behaviour of the GICTSAHPHE are evaluated.

The effectiveness of the GICTSAHPHE is formulated using the equation (1)

$$\text{Effectiveness } (\in) = \frac{Q_{actual}}{Q_{\max\ possible}} \qquad (1)$$

Maximum possible heat transfer ($Q_{max\ possible}$) is the product of minimum heat capacity rate (C_{min}) and maximum temperature difference (ΔT_{max}) is given equation (2)

$$Q_{max\ possible} = Cmin \times \Delta T_{max} \qquad (2)$$

Where

C_{min} is the least value of C_h or C_c are stated in the equations (3) and (4)

$$C_h = \dot{m}_h c_{ph} \qquad (3)$$

$$C_c = \dot{m}_c c_{p_c} \qquad (4)$$

Where C_h is the Hot fluid heat capacity rate is given in equation (3)

C_c is the Cold fluid heat capacity rate is given in equation (4)

In all set of experimentation $C_c < C_h$ i.e. $C_c = C_{min}$

Therefore, the effectiveness is calculated by the equations (5) and (6)

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

$$\in=\frac{\dot{m}_c c_{p_c}(T_{c_o}-T_{c_i})}{C_{\min}(T_{h_i}-T_{c_i})} \quad (5)$$

$$\in=\frac{T_{c_o}-T_{c_i}}{T_{h_i}-T_{c_i}} \quad (6)$$

The heat transfer rate is calculated by the mass flow rate of the fluid, specific heat of the fluid and temperature difference at entry and exit of fluid passing through the investigation. The energy balance equation can be given as follows in equations (7) and (8).

$$Q_h = \dot{m}_h c_{ph}(T_{hi} - T_{ho}) \quad (7)$$

$$Q_c = \dot{m}_c c_{pc}(T_{co} - T_{ci}) \quad (8)$$

Where Q_h is the Hot fluid heat transfer rate

Q_c is the Cold fluid heat transfer rate

A_c = Area of condenser section = $\pi D_c L_c N$ (9)

Using the above equation the convective heat transfer coefficient of cold fluid on GICTSAHPHE can be calculated by equation (10)

$$h = \frac{Qc}{A * (\Delta T)_{lm}} \quad (10)$$

The Reynolds number is measured by the mass flow rate of the fluid and condenser diameter of the heat pipe is calculated by the equation (11)

$$Re = \frac{4\dot{m}_c}{\pi D_c \mu} \quad (11)$$

D_c is the Condenser section diameter.

The Nusselt number is calculated by Reynold's number, Prandtl number and condenser diameter and is shown in equation (12)

$$Nu = 1.67\{\frac{Re*Pr}{x/D}\}^{0.333} \quad (12)$$

Friction Factor is determined by the function of Reynold's number. If Reynold's number increases the friction factor gets reduced is calculated by the equation (13)

$$f = \frac{64}{Re} (Re<2300) \quad (13)$$

Copper oxide with De-Ionized water mixture (CuO/DI) Nanofluid at volume concentration of 0.4% is calculated using the relations given in equations (14) and (15)

$$\text{Volume fraction} = \frac{Volume\ of\ Solute}{Volume\ of\ Solution} \quad (14)$$

$$\text{\% of Volume fraction} = \frac{Mass\ of\ Solute}{1000 \times Density} \quad (15)$$

3 Results and discussion

To investigate the fabricated GICTSAHPHE, the certain parameters are considered throughout the experimentation. The mass flow rates and temperatures of hot and cold fluids at an inlet conditions, inclination angles, geometrical parameters of condenser and evaporator sections, working fluid and heat transfer fluids are considered as parameters of the investigation. Heat transfer enhancement is observed by the following parameters which is used to predict the graphs in the investigation, Heat transfer rate, Effectiveness, Reynolds number, friction factor, Nusselt number and Heat transfer coefficient.

The experimentation is carried out by the stated parameters, Mass flow rates of hot fluids as 40 LPH, 60 LPH and 80 LPH, cold fluid as 20 LPH, 30 LPH and 40 LPH. The Temperature of hot fluids at the inlet as 50°C, 55°C and 60°C, cold fluid temperature is fixed as the ambient environmental temperature of the environment during the investigation as 33.5°C. Inclination angle as 10°, 30°, 50° and 70°. The working fluid is fixed as Methanol. Heat carrying fluid for first test rig as Water and second test rig as CuO/DI water (0.4 %).

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

Figure 4 depicts that, the effect of inclination angle on effectiveness with respect to the temperature of the hot fluid inlet with water as Heat transport fluid, the observed maximum hot fluid mass flow rate is 80 LPH for various inclination angles (ψ) as 10°, 30°, 50° and 70°. The observation stated that the increment of effectiveness is attained from 21.11% to 26.63 % for ψ as 10° and T_{hi} as 50°C to 60°C, while increasing inclination angle to 30° the observed effectiveness is 32.67% to 34.65%, for 50° the observed effectiveness is 36.47% to 39.6%, similarly for 70° the observed effectiveness is 34.1% to 37.3% for the same T_{hi} as 50°C to 60°C. It shows that increasing the temperature input of hot fluid and increasing the inclination angle the effectiveness of the system shows increasing in trends. At inclination angle of 70° for temperature increment, there is increasing in effectiveness is observed but while comparing to 50° of inclination angle effectiveness of the system gets reduced. It was inferred that at the higher hot fluid inlet temperature of GICTSAHPHE, the cold fluid temperature difference is higher due to maximum absorption and release of sensible heat by the WF. This shows that the effectiveness, increases by increasing the hot fluid mass flow rates and temperature inputs. The effect of gravity assistance shows inference in the observed result due to faster movement of working fluid along the condenser and evaporator section. This overcomes the friction along the working fluid. At increasing the inclination angle above 50° the effectiveness of system gets reduced due to the poor release of sensible heat to cold fluid by the methanol. The friction overcomes the movement of working fluid, after that the effectiveness starts to reduce due to the liquid film formation inside the heat pipe, which in turn reduces the heat absorption capacity of methanol in the heat pipe.

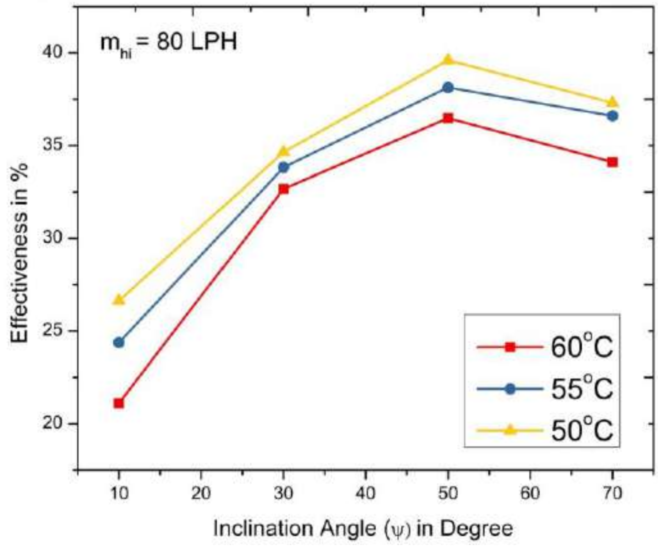

Figure 4. Effect of Inclination angle on Effectiveness (m_{hi} = 80 LPH, ψ = 10°, 30°, 50°, 70°)

Figure 5 predicts that effect of mass flow rate of hot fluid on effectiveness. This graph predicts that by using water as HTF and methanol as working fluid. The Hot fluid inlet temperature as 60°C and for varying m_{hi} from 40LPH to 80 LPH. The observed effectiveness for ψ at 10° is 24.59% to 26.63% it is 8.29% of increase in effectiveness, for ψ as 30° is 32.5% to 34.65% it is 6.67% of increase in effectiveness, for ψ as 50° is 35.54% to 39.6% it is 11.42% of increase in effectiveness, for ψ as 70° is 33.2% to 37.1% it is 11.74% of increase in effectiveness is observed. While comparing with ψ as 50° and 70° there is a decrement at effectiveness is observed from 7.04% to 6.73% for the same m_{hi} as 40 to 80 LPH. The effect of inclination angle along GICTSAHPHE induces the flow of working fluid along the system leads to the maximum temperature difference in condenser section which shows the increment at effectiveness is observed.

TEST Engineering & Management
January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

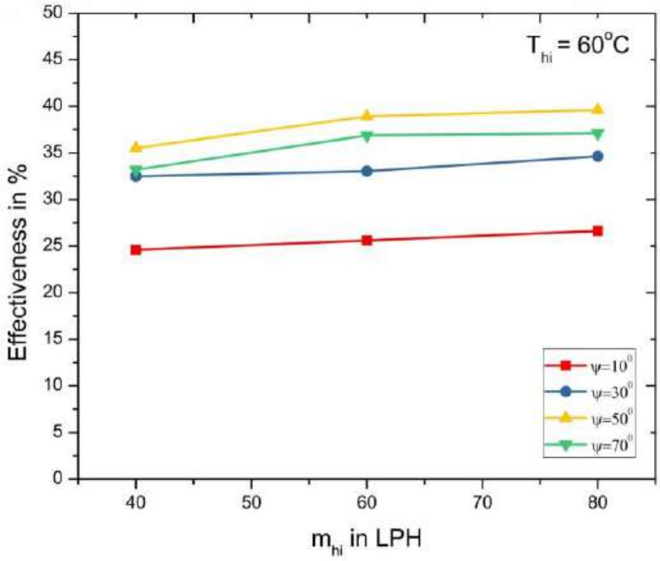

Figure 5. Effect of mass flow rate of hot fluid on Effectiveness (T_{hi} = 60 °C, Water)

The inclination angle above 50° the effectiveness of the system gets reduced due to formation of liquid film at vapour core region, which reduces the phase transformation of working fluid at evaporator region inside the heat pipe, this reduces the heat absorption capacity of methanol in the GICTSAHPHE.

Figure 6 depicts the effect of mass flow rate of hot fluid on effectiveness, this graph evident that for same above said conditions the effectiveness observed for ψ as 50°, CuO/DI water (0.4 % concentration) as HTF the viewed effectiveness is 56.25% to 63.34%, it is 12.60% increase in effectiveness, similarly for ψ as 70°, CuO/DI water (0.4 % concentration) as HTF the viewed effectiveness is 54.1% to 61.3%, it is 13.3% increase in effectiveness is observed. While comparing both ψ as 50° and ψ as 70° there is decrement at effectiveness in observed for 3.27% at 80 LPH condition. While comparing with water as heat transport fluid at the same inclination angle of ψ as 50° with CuO/DI water (0.4 % concentration) as HTF it shows 60% of an increase in effectiveness is observed. CuO/DI water (0.4 % concentration) shows a higher specific surface area thus maximum heat transfer surface between particles and fluids are achieved. It leads to the maximum heat carrying capacity over water this effects to higher temperature difference along the evaporator section.

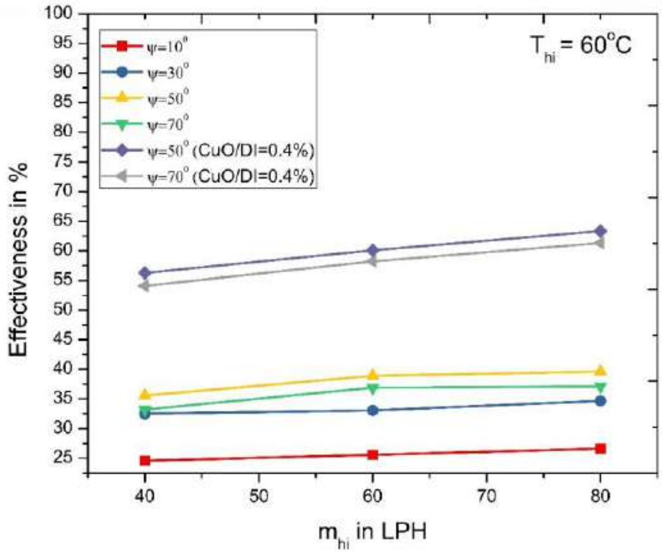

Figure 6. Effect of mass flow rate of hot fluid on Effectiveness (T_{hi} = 60 °C, CuO/DI water)

This transfer's maximum heat to the working fluid thus latent heat of vapourisation occurs. This vapour working fluid moves over vapour core area of heat pipe and reaches the condenser section. The influence of cold fluid makes the sensible heat of phase change to be occurred. Thus working fluid returns as liquid through wick by capillary action and influence of gravitational effect induces the movement of working fluid returning back to evaporator section. This temperature difference occurs with maximum mass flow rate condition shows higher the effectiveness of the system.

Figure 7 shows that effects of mass flow rate of hot fluid on heat transfer rate for water as HTF. The conditions for the observation are T_{hi} as 60°C, m_{hi} from 40LPH to 80 LPH and varying inclination angle from 10°, 30°, 50° and 70°. The heat transfer rate Q as 141.85W to 302.32W for ψ as 10°, ψ as 30° the observed Q as 205.62W to 446.5W, ψ as 50° the observed Q as 211.62W to 469.76W and ψ as 70° the observed Q as 211.17W to 458.8W. This increase in heat transfer rate is achieved by the maximum absorption of heat energy by the cold fluid at the condenser region. When the inlet temperature of the hot fluid at maximum range there is maximum heat transfer occurs between HTF and working fluid at the evaporator region. This leads to the increase of heat transfer rate while increasing the m_{hi} to 80 LPH, T_{hi} to 60ºC with an inclination angle of 50^o is shows an increment of 55.38% when compared with the same condition along ψ as 10 ^{o}. While comparing ψ as 50^o and 70^o there is a decrement in heat transfer rate of 2.38% is observed at 80 LPH. This decrease in trends shows lack of heat transfer from the optimum inclination angle of 50^o with a minimum release of sensible heat and effect of friction occurs at higher inclination angle due to gravitational effect at condenser region of the heat pipe.

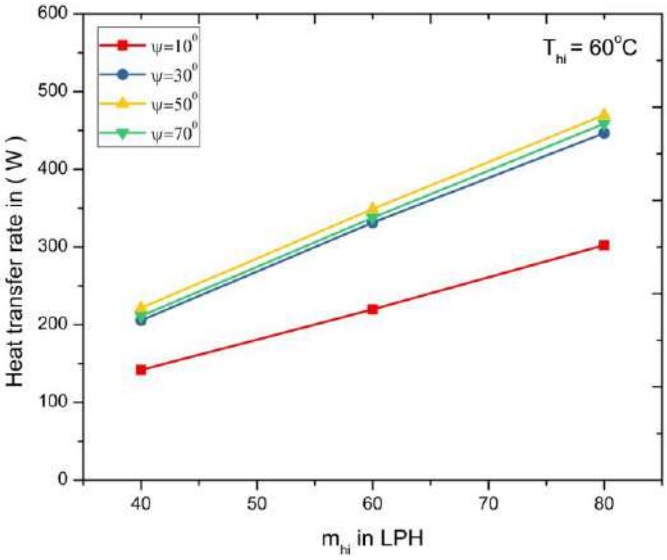

Figure 7. Effect of mass flow rate of hot fluid on Heat transfer rate (T_{hi} = 60 ºC, Water)

Figure 8 depicts the effects of mass flow rate of hot fluid on heat transfer rate, for similar above said conditions the heat transfer rate observed for CuO/DI water (0.4 % concentration) as HTF. This shows the high heat transport capacity which results in heat transfer rate Q as 282.73W to 607.17 W at ψ as 50^o. While ψ as 70^o the observed Q as 271.3 W to 596.2 W for 40 to 80 LPH at T_{hi} to 60ºC. In comparing with above condition the heat transfer rate evident with 29.25% of an increment than water as HTF at ψ as 50^o at 80 LPH and T_{hi} of 60ºC. Similarly like above Figure 7, here also while increasing the inclination angle to ψ as 70^o using of CuO/DI water (0.4 % concentration) as HTF there is 1.83% decrement at 80 LPH and T_{hi} of 60ºC when comparing with ψ as 50^o.

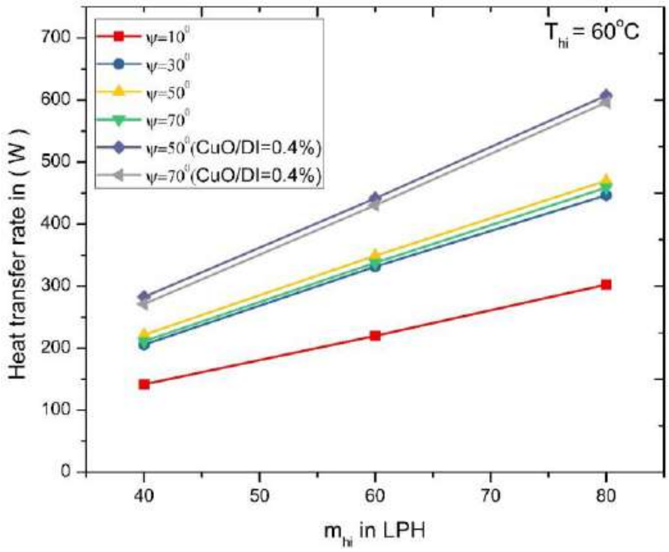

Figure 8. Effect of mass flow rate of hot fluid on Heat transfer rate (T_{hi} = 60 ºC, CuO/DI Water)

Figure 9 inferred that effects of mass flow rate of hot fluid on heat transfer coefficient with water as HTF. The conditions for observation are T_{hi} as 60ºC, m_{hi} from 40LPH to 80 LPH and varying inclination angle from 10^o, 30^o, 50^o and 70^o. The observed heat transfer coefficient h for ψ as 10^o is 161.83 W/m^{2}K to 362.55 W/m^{2}K, ψ as 30^o the value of h shows 220.91 W/m^{2}K to 477.02 W/m^{2}K, ψ as 50^o the h value observed as 253.87 W/m^{2}K to 589.03 W/m^{2}K and for ψ as 70^o the observed value is 241.12 W/m^{2}K to 577.33 W/m^{2}K. This is due to the higher release of sensible heat to the cold fluid, by the working fluid which leads to maximum heat transfer along the system.

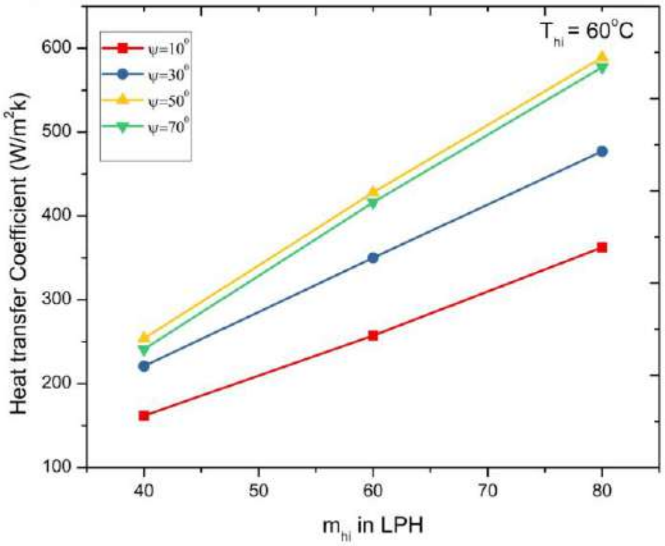

Figure 9. Effect of mass flow rate of hot fluid on Heat transfer coefficient (T_{hi} = 60 °C, Water)

This predicts the higher heat transfer coefficient at hot fluid for maximum mass flow rates and temperature input with the high inclination angle. While comparing the ψ as 10° and 50° at 80 LPH there is 62.46% increment is viewed similarly, by comparing ψ as 50° and 70° there is decrement of 2.02% at 80 LPH this shows the optimum inclination angle is ψ as 50°.

Figure 10 predicts the effects of mass flow rates of hot fluid on heat transfer coefficient for CuO/DI water (0.4 % concentration) as HTF. Similar above revealed conditions the heat transfer coefficient (h) observed is 528.36 W/m^2K to 1021.37 W/m^2K for ψ as 50°. At an increased inclination angle of ψ as 70° the observed h value is 517.34 W/m^2K to 1009.36 W/m^2K. While comparing with the previous observation from Figure 9, the h shows the increment of 73.39% at 80 LPH for ψ as 50° and T_{hi} of 60°C than water as HTF. High dispersion stability of CuO/DI water (0.4 % concentration) apparent with the high thermal conductivity of the flowing fluid it leads to the higher heat transfer with cold fluid it shows maximum heat transfer coefficient of GICTSAHPHE. Similarly, as above Figure 8 by comparing the ψ as 50° and 70° and CuO/DI water (0.4 % concentration) as HTF there is 1.18% decrement at 80 LPH while increasing above optimum inclination angle.

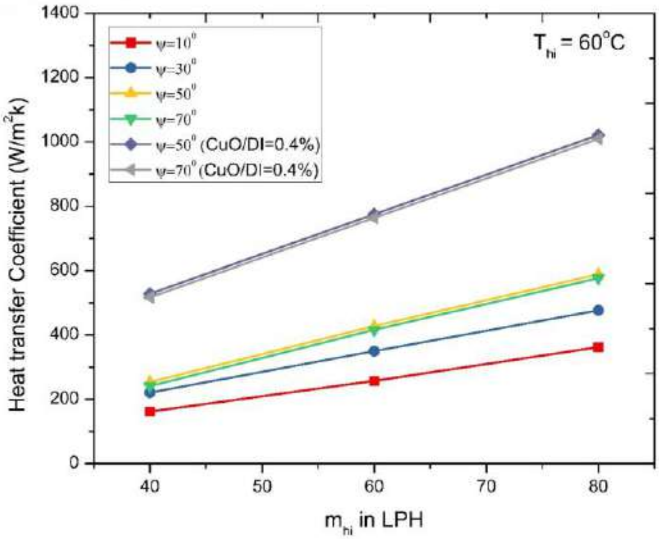

Figure 10. Effect of mass flow rate of hot fluid on Heat transfer coefficient (T_{hi} = 60 °C, CuO/DI Water)

Figure 11 observes the effects of mass flow rates of the hot fluid on Reynold's number. At the inlet conditions for the inclination angles from 10°, 30°, 50° and 70°, Temperature of T_{hi} as 60°C and m_{hi} from 40LPH to 80 LPH and water as HTF. The observed Reynold's number (Re) ranges from 283.17 to 576.26 at ψ as 10°, ψ as 30° the observed Re as 294.77 to 597.86, ψ as 50° the Re value found as 300.15 to 609.52 and ψ as 70° the observed Re value as 295.9 to 604.59. This shows that while increasing the quantity of the hot fluid mass flow rate, Reynold's number increases gradually to 5.77% at 80 LPH while comparing ψ as 10° and 50°. This is evident that increasing mass flow rate of hot fluid transfers maximum heat to the working fluid and which results in high heat absorption capacity. Similarly, while increasing the gravitational angle above the optimum condition the formation of the liquid film in heat pipe decreases the heat transfer capacity in working fluid it shows 0.81% of decrement while comparing ψ as 50° and 70° at 80 LPH.

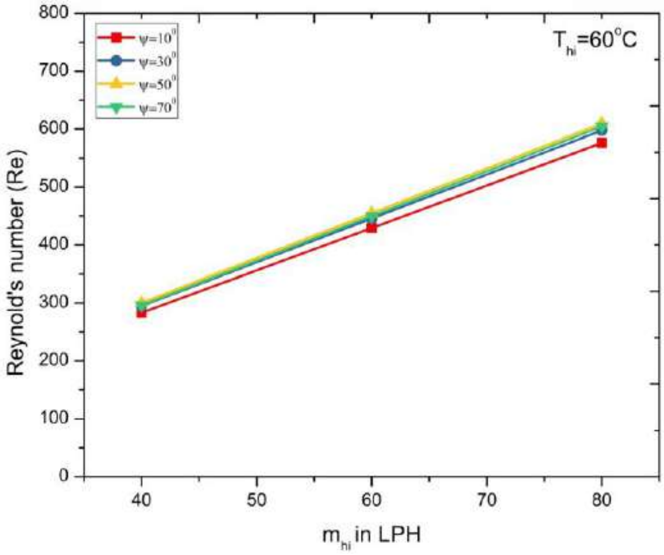

Figure 11. Effect of Mass flow rate of hot fluid on Reynold's number (T_{hi} = 60 °C, Water)

In Figure 12 this graph shows Effects of mass flow rates of hot fluid on Reynold's number for both water and CuO/DI water (0.4 % concentration) as HTF are evaluated. The observation of CuO/DI water (0.4 % concentration) shows Reynold's number ranges from 620.48 to 646.86 for ψ as 50° and 614.7 to 640.9 ψ as 70°. This is the maximum Reynold's number for the condition, thus flow behaves as laminar throughout the investigation. In this analysis by comparing the both conditions the observed Reynold's number evident with 6.12% increasing than water as HTF at 80 LPH for ψ as 50°. Similarly, like above graph shown in Figure 11 there is decrement of 0.92% for ψ as 50° and 70° at 80 LPH.

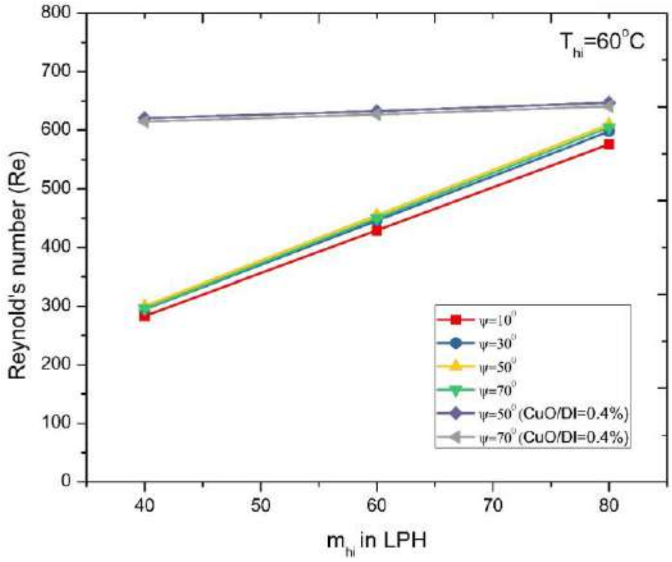

Figure 12. Effect of Mass flow rate of hot fluid on Reynold's number (T_{hi} = 60 °C, CuO/DI Water)

Figure 13 depicts that Effects Reynold's number over the Nusselt number for both the conditions of HTF are analysed. The conditions for the investigation are m_{hi} from 40 LPH to 80 LPH, T_{hi} as 60°C and inclination angle from 10°, 30°, 50° and 70°. The Nusselt number ranges from 11.38 to 14.3 at ψ as 10°, ψ as 30° it is 12.35 to 14.48, ψ as 50° observed Nu is 12.43 to 14.86 and ψ as 70° it is 12.4 to 14.51 for the above-stated condition for water as HTF. A Similar type of increasing in trends are observed for CuO/DI water (0.4 % concentration) as HTF the Nu value is 15.1 to 15.86 for ψ as 50° and 14.92 to 15.71 at ψ as 70°. The observed Nusselt number reveals that by increasing Reynold's number the observed Nu value also increased in all the conditions. While increasing the inclination angle above ψ as 50° Reynold's number gets reduced similarly Nusselt number also shows decreasing in trends of 2.41% for ψ as 70° and water as HTF. Similarly, for CuO/DI water (0.4 % concentration) as HTF also shows 0.95% of decrement over ψ as 70° than ψ as 50°.

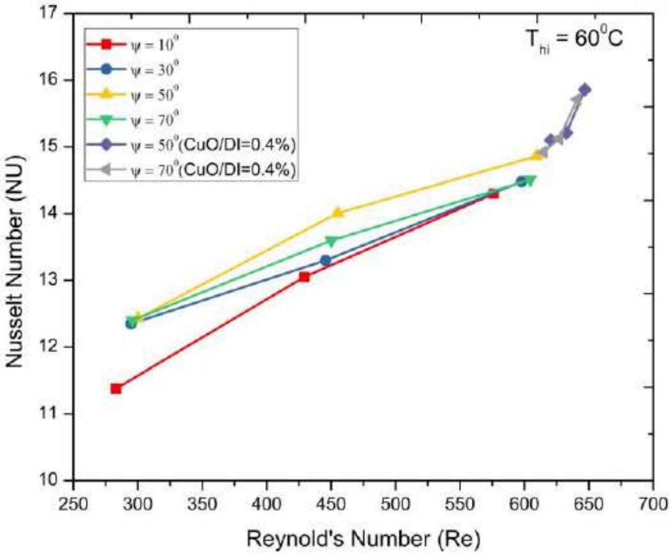

Figure 13. Effect of Reynold's number over Nusselt number (T_{hi} = 60 °C, CuO/DI Water)

The above said conditions of both HTF are analysed this shows that there is 6.74% increase in Nusselt number is observed over water as HTF at ψ as 50° for 80 LPH.

Figure 14 determines the Effects of Friction factor over Reynold's number for both HTF are investigated. In water as HTF the analysis are carried out for T_{hi} as 60°C, m_{hi} from 40 LPH to 80 LPH and inclination angles from 10°, 30°, 50° and 70°. The friction factor shows that 0.2265 to 0.1082 for ψ as 10°, 0.2171 to 0.1069 for ψ as 30°, 0.2132 to 0.105 for ψ as 50° and 0.2162 to 0.1055 for ψ as 70°. The similar decreasing in trends are observed for above revealed conditions for CuO/DI water (0.4 % concentration) for ψ as 50° friction factor shows 0.205 to 0.1011 and 0.2061 to 0.1015 for ψ as 70°. This friction factor value shows that by increasing Reynold's number the friction factor gets decreased with consideration of mass flow rates of hot fluids. While increasing the inclination angle above ψ as 50° Reynold's number gets decreased while friction factor gets increased. In comparing the both conditions of HTF there is 3.85% of decrement is observed than water as HTF.

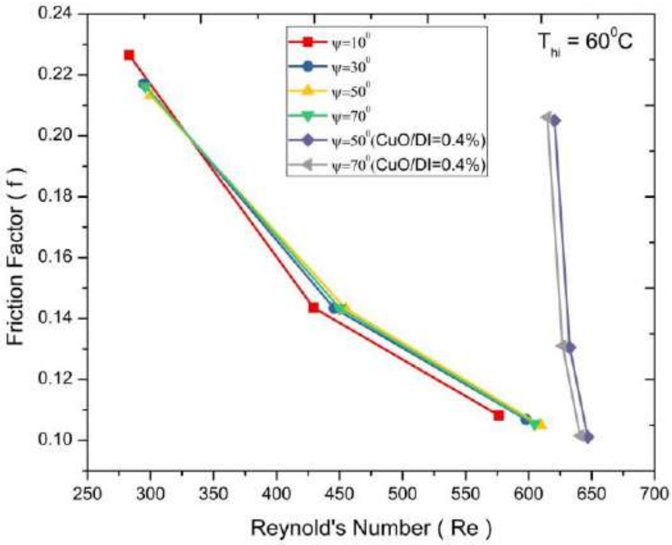

Figure 14. Effect of Reynold's number over Friction factor (T_{hi} = 60 °C, CuO/DI Water)

This is evident that increasing in Reynold's number leads to decrement in friction factor. Similarly decreasing in Re at ψ as 70° for both HTF conditions shows an increase in friction factor of 0.47% at water as HTF and 0.39% at CuO/DI water (0.4 % concentration) as HTF.

4 Conclusion

In this GICTSAHPHE experimentation, the influence of HTF on heat pipe shows predominant improvement in investigation. The heat transfer enhancement is observed along the CuO/DI water than water as HTF. The geometrical parameter of the system shows the wide range of improvement in the analysis. The influence of inclination angle induces the movement of WF along the heat pipe with a higher rate of heat transfer in the system.

- It is inferred that optimum revealed conditions observed from the investigation are hot fluid mass flow rates (m_{hi}) as 80 LPH and cold fluid (m_{ci}) as 40 LPH, Temperature of hot fluid at inlet(T_{hi}) as 60°C, the inclination angle (ψ) as 50°.
- **Test 1:** Investigation for water as HTF reveals that for m_{hi} of 80 LPH, T_{hi} of 60°C and ψ as 50° the effectiveness observed is

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

39.6% it is 48.70% of increment in effectiveness than ψ as 10°.

- In the same revealed conditions the heat transfer coefficient (h) and heat transfer rate (Q) obtained is 589.03W/m^{2}K it is 62.46% increases and 469.76W it is 55.38 % increment than ψ as 10°.
- Reynold's number ranges at 609.52 at same above stated conditions it is 5.77% increment than ψ as 10° thus flow behaves laminar.
- Effect of the Nusselt number shows 14.86 it is 3.91% increment than above-stated inclination angle.
- Friction factor shows 0.105 it is 3.04% of decrement than stated conditions.
- **Test 2:** In CuO/DI water (0.4 % concentration) investigation reports that for m_{hi} of 80 LPH, T_{hi} of 60°C and (ψ) as 50° the effectiveness observed is 63.34% it is 60% of an increment than water as HTF for the same condition.
- In the above revealed conditions the heat transfer coefficient (h) and heat transfer rate (Q) observed is 1021.37W/m^{2}K it is 73.4% that water as HTF and 607.17 W it is 29.3% than water as HTF.
- Reynold's number ranges around 646.86 it increases by 6.12%, comparing both tests of GICTSAHPHE.
- The effects of Reynolds number along Nusselt number shows 15.86 leads to the increment of 6.74% for the same revealed condition.
- Friction factor shows the 0.1011 it is 3.85% of decrement as the stated condition of inclination angle.
- Effect of inclination angle along the experimentation shows the improvement in all the conditions. In all the stated inclination angle (ψ) as 70° shows decrement in all the revealed conditions than ψ as 50°, it is observed in all over the investigation for both HTF are given below.
- In water as HTF and for optimum conditions, the decrement in an analysis is observed for effectiveness as 6.73%, heat transfer rate shows 2.38%, heat transfer coefficient as 2.02%, Reynold's number depicts 0.81%, The Nusselt number gives 2.41% and friction factor shows an increment of 0.47%.
- In CuO/DI water (0.4 % concentration) as HTF and for revealed optimum conditions, the similar decrease in trends are viewed for effectiveness as 3.27%, heat transfer rate shows 1.83%, heat transfer coefficient depicts 1.18%, Reynold's number as 0.92%, Nusselt number gives 0.95% and friction factor shows increment of 0.39%.
- This investigation shows clearly that optimum conditions for the investigation are observed with an inclination angle of (ψ) as 50° with CuO/DI water (0.4 % concentration).

References

[1] Ivanovskii, M. N.; Sorokin, V. P.; and Yagodkin, I. V.: The physical principles of heat pipes. Oxford University Press. 1982.

[2] Noie-Baghban, S. H.; Majideian, G. R.: Waste heat recovery using heat pipe heat exchanger (HPHE) for surgery rooms in hospitals. Applied Thermal Engineering.**20**, 1271-1282 (2000)

[3] Khalid Joudi, A.; Witwit, A. M.: Improvements of gravity assisted wickless heat pipes. Energy Conversion and Management.**41**, 2041-2061(2000)

[4] Nozu, S.: Studies related to the heat pipe. Trans. Soc. Mechanical Engineering.**35**, 392-401(1969)

[5] Azad, E.; Geoola, F.: A design procedure for gravity assisted heat pipe heat exchanger. Heat Recovery System.**4**, 101-111(1984)

January - February 2020
ISSN: 0193 - 4120 Page No. 1623 - 1638

[6] Azad, E.; Bahar, F.; Moztarzadeh, F.: Design of water to air gravity assisted heat pipe heat exchanger. Heat recovery system. **5**, 89-99(1985)

[7] Tan, J. O.; Liu, C. Y.: Predicting the performance of a heat pipe heat exchanger using the effectiveness NTU method. International Journal of heat and Fluid flow.**11**, 376-379(1990)

[8] AlicetinGurses; Cannistrano, C.: The inclination effect on the performance of water-filled heat pipes. Renewable Energy.**1**, 667-674(1991)

[9] RaffaeleSavino; Yoshiyuki Abe; RaimondoFortezza: Comparative study of heat pipes with different working fluids under normal gravity and micro gravity conditions. PERGAMON. Acta Astronautica. **63**, 24-34(2008)

[10] Esarte, J.; Domiguez, M.: Experimental analysis of a flat heat-pipe working against gravity. Applied Thermal Engineering.**23**,1619-1627 (2003)

[11] Shabgard, H ; Bergman, T.L; Shariti, N and Faghri, A.: “High temperature latent heat thermal energy storage using heat pipes”, International Journal of Heat and Mass Transfer.**53**,2979-2988 (2010)

[12] Kempers, R.; Ewing, D.; Ching, C. Y.: Effect of number of mesh layers and fluid loading on the performance of screen mesh wicked heat pipes. Applied Thermal Engineering.**26**, 89-595(2006)

[13] Said Salem, A and Bilal Akash, A.: “Experimental performance of a heat pipe”, International Communication of Heat and Mass Transfer.**26 (5)**, pp.679-684 (1999)

[14] MasoudRahimi; KayvanAsgary; SiminJesri: Thermal characteristic of a resurfaced condenser and evaporator closed two-phase thermosyphon. International Communications in Heat and Mass Transfer.**37**, 703-710(2010)

[15] Shimura, T.; Sho, H.; Nakamura, Y.: The Aluminum Flat heat pipe using Cyclopentane as working fluid. I Therm Proceeding.224-229(2002)

[16] Mangal Singh Lodhi; Gupta, R. C.: The experimental study of the thermal performance of Heat pipe using CuO/water nanofluid. International Journal of Engineering Science and Research Technology. **2,**2048-2054(2013)

[17] Wongcharce, K.; Elamsa-ard, S.: Enhancement of heat transfer using CuO/water nanofluid and twisted tape with alternate axis. International Communications in Heat and Mass Transfer. **38**, 742-748(2011)

[18] Hasanuzzaman, M.; Saidu, R.; Rahim, N. A.: Effectiveness enhancement of heat exchanger by using Nanofluids. IEEE first conference on clean energy and technology.**11**, 98-103(2011)

[19] Shafai, M; Blanoco, V; Vafai, K; and Manco, O.: “An investigation of the thermal performance of cylindrical heat pipes using nanofluid”, International Journal of Heat and Mass Transfer, **53**, 376-383, (2010)

[20] Durga Bastakoti; Hongna Zhang; WeihuaCai; Fengchen Li: An experimental investigation of thermal performance of pulsating heat pipe with alcohols and surfactant solutions. International Journal of Heat and Mass Transfer.**117**, 1032–1040(2018)