IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

The Experimental Study of the Thermal Performance of Heat Pipe using CuO/Water Nanofluid

Mangal Singh Lodhi[*1], **Prof. R. C. Gupta**[2]
[*1]Research scholar, Fourth Semester, M. E. (Heat Power Engineering) Jabalpur Engineering College, Jabalpur (MP)-482011,India
[2]Associate Professor, Department Of Mechanical Engineering Jabalpur Engineering College, Jabalpur (MP)-482011, India
mangalsingh1988@yahoo.com

Abstract

This paper presents the enhancement of the thermal performance of a heat pipe charged with nanofluid. The CuO/Water nanofluid served as the working fluid with three concentrations by volume 1g/L, 5g/L and 10g/L in heat pipe. The heat pipe is fabricated by a straight copper tube with an outer diameter 18 mm, thickness 1mm and length of 475 mm. This paper presents a discussion on the effect of various performing parameters by varying different heat inputs as well as fluid concentration as mentioned above. The nanoparticles have observed significant effect on the enhancement of thermal performance of heat pipe by increasing fluid concentration as well as different heat inputs. Experimental results show that at a heating power of 80 W, the optimal thermal conductivity and heat transfer rate for CuO/Water nanofluid heat pipe are 50.46% and 1.75% respectively, which are better than that of pipes using pure water as the working fluid.

Keywords: Heat Pipe, Thermal Performance, Nanofluid, CuO nanoparticles, Fluid Concentrations.

Nomenclature:
dx: Thickness (m)
dT: Temperature difference (^{0C})
k: Thermal conductivity [W/m K]
R_{HP}: Total thermal resistance (^{0}C/W)
A_s: Surface Area (m^2)
V_{HP}: Total Volume of heat pipe (L)
D: Outer diameter (m)
t: Thickness (m)
k_{HP}: Overall thermal conductivity of heat pipe (W/m^{0}C)
L: Length of the heat pipe (m)
Qin: Heat transfer rate (heating power) (W)
V: Voltage (V)
I: current (A)
Q_{out}: outlet heat by condensation (W)
T_{in}: Inlet temperature of cooling water (K)
T_{out}: Outlet temperature of cooling water (K)
$\dot{m}_l$: mass flow rate of water (Kg/s)
V_l: Volume flow rate of liquid (L/sec.)
C_P : Specific heat of water (J/kg K)
ΔT: Temperature difference (K)

Subscripts
Out: output
In: input
l: liquid (cooling water)
HP: heat pipe
c: Condensation section
a: Adiabatic section
e: Evaporation section

Greek symbols
ρ: Density of water (Kg/m^3)
η: Thermal efficiency of heat pipe (%)
ω: Fluid concentration (g/L)
Δ: Change/Difference

Acronyms
TPCT: Two-Phase Closed Thermosyphon
PHPs: Pulsating Heat Pipes
OHPs: Oscillating Heat Pipes
HP: Heat Pipe

Introduction

For the past many years, two-phase passive heat transfer devices like heat pipes and thermosyphons have played an important role in a variety of engineering heat transfer systems, ranging from electronics thermal management to heat exchangers and reboilers. In this context, the present scenario of high thermal loading coupled with high flux levels demands exploration of new heat transfer augmentation mechanisms besides the conventional techniques. 'Nanofluids' are fast emerging as alternatives to conventional heat transfer fluids. Although recent studies have shown some conflicting trends with regards to their thermo-hydrodynamic behaviour, there are enough indications that exploratory research is indeed required to bench mark the scope and applicability of these fluids in engineering systems [4].

A heat pipe is an excellent heat conductor, one end of a heat pipe is the evaporation section and the other end is the condensation section. When the evaporation section is heated, the liquid in the heat pipe evaporates rapidly. This vapour releases its heat at the condensation section, which has a small vapour pressure difference, and condenses back into liquid. The condensed liquid in the condensation section then flows back to the evaporation section along the inner wall of the heat pipe and undergoes endothermic evaporation in the evaporation section. The heat transfer of a heat pipe uses a working fluid that changes phases in a continuous endothermic and exothermic cycle, giving the heat pipe excellent heat transfer performance [17].

The common types of heat pipes primarily include as: Two-Phase Closed Thermosyphon (TPCT) heat pipes, Pulsating Heat Pipes (PHPs) and Oscillating Heat Pipes (OHPs) [17].

Heat pipes are used extensively in various applications, for achieving high rates of heat transfer utilizing evaporation and condensation processes. Heat pipes have been used in spacecrafts, computers, solar systems, heat and ventilating air conditioning systems and many other applications [14]. Heat pipes have been used in various applications, including Air-Conditioning Systems, the cooling of Electronic components, Thermal storage, and Solar Heating systems [17].

In recent times, there has been an urgent need in many industrial fields for a new cooling medium with significantly improved heat transfer performance compared to those currently available and it is also well known that fluids typically have lower thermal conductivity compared to crystalline solids. Therefore, fluids containing suspended solid particles can be reasonably expected to have higher thermal conductivities than pure fluids. The idea of using nanofluids, defined as liquids with nanometre-sized particle suspensions, was first introduced by Choi in 1995. It has been shown that when solid nanometre-sized particles are suspended in fluid, the enhancement of thermal conductivity can be significant. This enhancement can improve the efficiency of fluids used in heat transfer applications [17].

Nanofluid is a stable solid-liquid suspension created by mixing of nanoparticles with the traditional working fluid. The nanoparticles in the heat pipe nanofluid include metal particles Diamond and Oxide particles [17]. Different nanoparticles such as Gold, Silver, Diamond, Alumina, Titanium, Copper oxide, Nickel oxide and Iron oxide have been utilized with in thermosyphons and Heat pipe as a working fluid [12]. A common range of concentration for different nanoparticles, namely Al_2O_3, CuO, and TiO_2 in water is considered as the operational fluid within the heat pipe under various heat inputs [9].The following literature review describes important research summary regarding the nanofluids used in heat pipes in table-1 given below as:

"Table-1 Summary of some important Literature Review"

S. No	AUTHOR	Nano Fluid	Nanoparticle Size(nm)	Fluid Concentration	Description of Experimental Setup
1.	Wang et al (1999)[1]	Al_2O_3/Water	28	4.5%	-
2.	Lee et al. (1999)[2]	CuO/Water, Al_2O_3/Water	18.6, 24.4	4.3%	-
3.	Das et al. (2003)[3]	Al_2O_3/Water	38	4%	-
4.	Kang et al.(2009)[5]	Ag/Water	10-35	1mg/L,10mg/L,100mg/L	-
5.	S.H. Noie et al.(2009)[6]	Al_2O_3/Water	20	1-3%	ID=20 mm, Length=1000 mm
6.	P. Naphon et al.(2009)[7]	TiO_2/R-11	21	0.1%	OD=15 mm, Length=600 mm
7.	Liu et al. (2010)[8]	CuO/Water		1%	-
8.	Ji et al. (2011)[10]	Al_2O_3/Water	80	-	-
9.	Humanic and Humanic et al.(2011)[11]	Fe_3O_4/Water	4-5	0.0%, 2.0%, 5.3%	OD=15 mm, Length=2000 mm
10.	Qu and Wu et al. (2011)[13]	SiO_2/Water, Al_2O_3/Water	30, 56	0-0.6 %, 0-0.12%	OD=3mm, Length=3000mm
11.	A.B. Solomon et al.(2012)[14]	CuO/Water	80-90	-	OD=19.5 mm, Length=400 mm

12.	Hajian et al. (2012)[16]	Ag/DI water	-	50ppm,200ppm,600ppm	-
13.	Yi-Hsuan Hung et al. (2013)[17]	Al_2O_3/Water	10-30	0.5%,1.0%,3.0%	OD=9.52mm, Length=1350 mm

Experimental Setup Details

Preparation of Nanofluid:

The CuO/Water Nanofluid used in this study contains commercial nanoparticles of purity of 99.0%. The Nanoparticles are in the size range of 30-50 nm. The Nanoparticle with this size range is chosen for a performance comparison with the heat pipe operated with nanofluid prepared using the same size particles. The thermo physical properties of CuO nanoparticles are shown below in table-2 as:

“Table-2 The thermo physical properties of CuO nanoparticles

S.No.	Properties of nanoparticles	Values
1.	Colour and appearance	Brown Powder
2.	Particle size(nm)	30-50
3.	Thermal Conductivity(W/mK)	18
4.	Purity (%)	99.0
5.	Density(Kg/m^3)	6510
6.	Specific Heat(J/KgK)	540

A nanofluid is prepared by mixing 1g of copper nanoparticles with 1 L of distilled water. Mixing of nanoparticles with distilled water is carried out by direct-synthesis method. The CuO/Water nanofluid produced using the direct-synthesis method was then adopted as the experimental sample. The CuO/Water nanofluids were statically placed for 2 weeks to confirm suspension performance.

Experimental Apparatus and procedure:

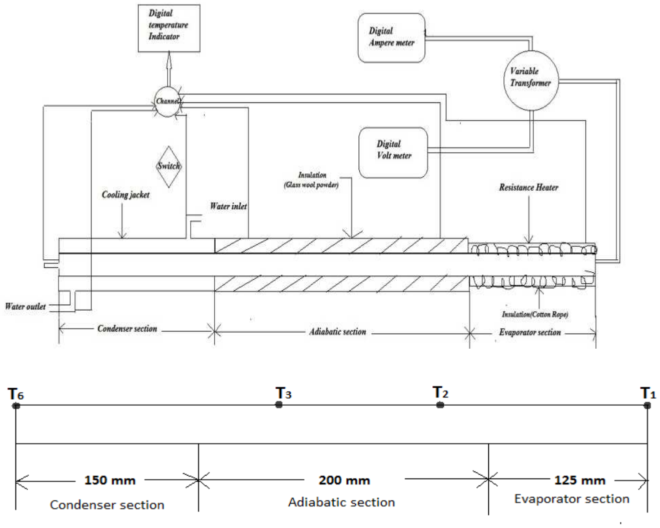
The heat pipe in this study was made of straight copper tubing with an outer diameter of 18 mm, 1 mm thickness and length of 475 mm. It mainly divided three different sections such as evaporator section, adiabatic section and condenser sections lengths of 125 mm, 200 mm and 150 mm respectively. The technical specification of Heat pipe is given below in table-3 as:

Table-3 Technical specification of Heat pipe”

S. No.	Components	Dimensions(mm)	Materials
1.	Heat pipe (straight copper tube)	Length(L) = 475 mm Outer dia(D) =18 mm Thickness(t) = 1 mm	Copper
	Evaporation section	L_e = 125 mm	
	Adiabatic section	L_a = 200 mm	
	Condensation section	L_c = 150 mm	
	Total Surface Area of Heat pipe	A_s =0.0268 m^2	
	Total Volume of Heat Pipe	V_{HP} = 0.0955 L	
2.	Insulating materials	Thickness=10 mm	Glass Wool Powder
3.	Cooling Jacket(MS Pipe)	Length=150 mm	Mild Steel

The experimental setup mainly consists of a Resistance heater, Digital A/V meter and Variable transformer to provide the necessary power to the Resistance heater. The temperatures on the heat pipe were measured using a Digital temperature indicator with four thermocouples (J-type) at different points. The accuracy of temperature measurements was ±0.50C.

The Digital temperature indicator is used to record the thermocouple readings at different positions of the heat pipe. Thermocouples of J-type (4 numbers) are used to measure the temperature at the different sections of the heat pipe. In total four thermocouples were attached on the heat pipe wall, i.e. two at both the evaporation and condenser section, and two at the adiabatic section. The thermocouples are welded over the surface of the heat pipe as shown in figure-1 below:



"Fig. 1 (a) Layout of experimental setup of heat pipe (b) Typical drawing of heat pipe with arrangement of thermocouple"

The entire heat pipe is insulated by using glass wool powder to avoid heat loss from the system. A cooling jacket, which consists of inlet and outlet ports for cooling water, is fabricated using mild steel pipe. The temperature of cooling water at the inlet and outlet are measured using J-type thermocouples. The briefdescription of various measuring instruments is given in the table-4 below as

"Table-4 The brief description of various measuring instruments"

S.No.	Instruments	Capacity	Quantity
1.	Resistance heater	200 W	1
2.	Digital Ammeter	5 A	1
3.	Digital Volt Meter	270 V	1
4.	Digital Temp. Indicator	400^{0}C	1
5.	Variable Transformer	2 A	1
6.	Thermocouple(J- type)	700^{0}C	6

The locations of Thermocouple on Heat pipe is given in the table-5 below as:

"Table - 5 Locations of Thermocouple used in heat pipe"

Thermocouple Number	Heat Pipe Location	Distance from Evaporator end cap(cm)
1	Evaporator Heater	5
2	Adiabatic section	15
3	Adiabatic section	23
4	Cooling jacket outlet	35
5	Cooling Jacket inlet	45
6	Condenser Section	48

The heat pipe was charged with 25 ml of nanofluid at different fluid concentrations as 1 g/L, 5 g/L and 10g/L respectively. An AC power supply is the source of power for the cylindrical resistance heater, used for heating of the evaporator section. The heating power in the evaporation section was kept at 30W, 50W and 80W by variable transformer with variable power supply of resistance heater at an accuracy of ± 0.5W. The cooling jacket in the condensation section contained cooling water inside a mild steel pipe. This allowed the water tank to provide cooling water at a temperature of 25±0.5 ^{0}C. The flow rate of cooling water is measured when the heat pipe attains steady state conditions. It is adjusted to get the temperature difference of 3-4 ^{0}C. The test of heat pipe performance was with varying parameters such as fluid concentrations (ώ) and heat in power (W). The overall thermal Conductivity of the heat pipe was then calculated using Eq. (2) to evaluate its thermal performance.

Uncertainty Analysis:

The uncertainty of the experimental results was determined based on the deviation in experimental parameters. The overall thermal conductivity of the heat pipe was calculated based on the readings of the variable power supply. The length of the heat pipe was measured using a steel ruler. The temperature was determined using J-type thermocouples. Uncertainty of the overall thermal conductivity for the heat pipe can be expressed as:

$$\mathrm{Um,kHP} = \left[\frac{\Delta \mathrm{Qin}}{\mathrm{Qin}} + \frac{\Delta\omega}{\omega} + \frac{\Delta \mathrm{T}}{\mathrm{T}}\right]0.5$$

The accuracy of the programmable power supply is ±0.5 W. The accuracy of the steel ruler is ±1.0 mm. The accuracy of the thermocouples is ±0.5^{0}C [17]. The accuracy of various measuring instruments is given in table-6 below as:

“Table-6: The accuracy of various measuring instruments”

S. No.	Measuring Instruments	Accuracy
1.	Resistance heater	±0.5 W
2.	Variable Transformer	±0.01A
3.	Thermocouple(J- type)	±0.5^{0}C
4.	The Steel Ruler	±1.0 mm

Mathematical Formulation

The heat conduction rate of a one-dimensional plane wall under a steady-state condition can be described by Fourier’s law and expressed as:

$$q = -k\frac{dT}{dx} \qquad (1)$$

The heat flux q (W/m^2) is the rate of heat transfer in the heat conduction direction per unit area, and is proportional to the temperature gradient (dT/dx). The proportionality constant k is a transport property known as thermal conductivity, and is a characteristic of the wall material.

The overall Thermal conductivity (k_{HP}) of Heat pipe is defined as follows:

$$\mathrm{kHP} = \frac{Qin * L}{A\Delta T} \qquad (2)$$

Where A is the actual area of heating and heat dissipation, L is the length of the heat pipe, ΔT is the temperature difference between the evaporation and condensation section, and Q_{in} is the heating power.

The heat load i.e. heating power of the Heat Pipe which is calculated by follows:

$$\mathrm{Qin} = \mathrm{VI} \qquad (3)$$

Where **V** and **I** are the input voltage and current measured by the digital multi meter.

The heat transferred by the heat pipe is calculated using the heat balance equation as:

$$Qout = \dot{m}lCp(Tout - Tin) \qquad (4)$$

Where $\dot{m}_l = \rho V_l$

The overall thermal resistance (R_{HP}) is a measure of thermal performance of heat pipe, which is defined as:

$$\mathrm{RHP} = \frac{\Delta T}{Qout} \qquad (5)$$

Where $\Delta T = T_e - T_c$.

The efficiency of heat pipe can be expressed as a ratio of the output heat by condensation to the inlet heat by evaporation, i.e.

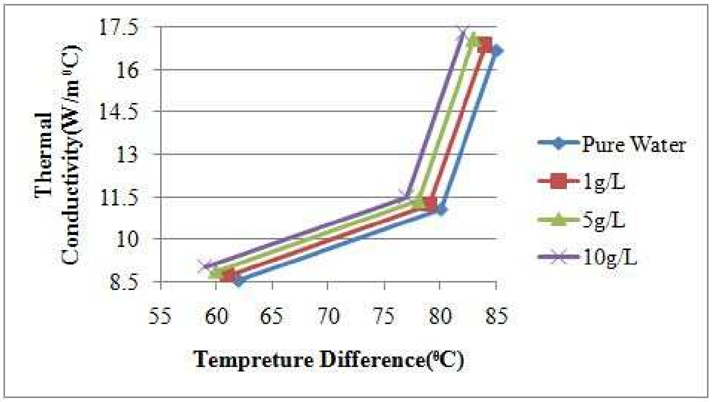
$$\eta HP = \frac{\mathrm{Qout}}{\mathrm{Qin}} \qquad (6)$$

Results and Discussions

Effect of temperature difference on the overall thermal conductivity of heat pipe:

The overall Thermal conductivity (k_{HP}) of Heat pipe is defined as follows:

$$\mathrm{kHP} = \frac{Qin * L}{A\Delta T} \qquad \text{Where} \quad \mathbf{Qin = VI}$$



“Fig. 4.1 Effect of temperature difference on the overall thermal conductivity of heat pipe”

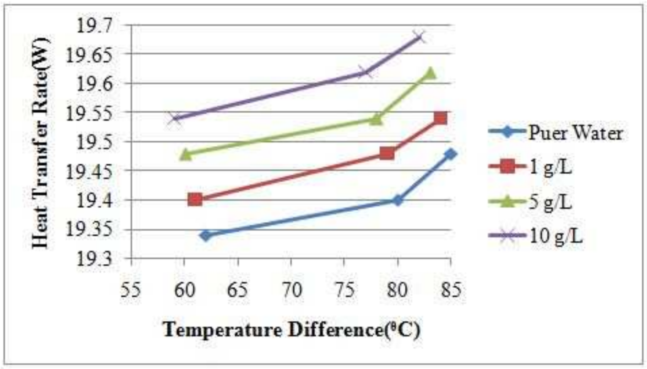
Fig. 4.1 shows the changes in the overall thermal conductivity of the heat pipe for various heating power, as well as different fluid concentration values of CuO/Water nanofluid heat pipe.

The figure shows that the overall thermal conductivity of heat pipe increases as concentration of nanofluid increases. The experimental result shows that the maximum value of overall thermal conductivity17.30W/m^{0}C is obtained at 80 W with 10 g/L nanofluid which is 50.46 % more than that of pure water.

Effect of temperature difference on the heat transfer rate of heat pipe:

The heat transferred by the heat pipe is calculated using the heat balance equation as:

$$Qout = \dot{m}lCp(Tout - Tin)$$, Where $\dot{m}_l = \rho V_l$



“Fig. 4.2 Effect of fluid concentration on the heat transfer rate of heat pipe”

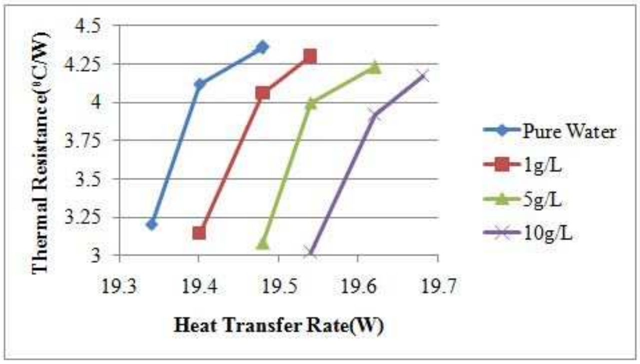
Fig. 4.2 shows the changes in the Heat transfer rate of the heat pipe for various heating power, as well as different fluid concentration values of CuO/Water nanofluid heat pipe

The figure shows that the heat transfer rate increases as concentration of nanofluid increases. The experimental result shows that the maximum value of heat transfer rate is obtained 19.68 W at 80 W with 10 g/L nanofluid which is 1.75 % more than that of pure water.

Effect of the heat transfer rate on overall thermal resistance of heat pipe:

The overall thermal resistance (R_{HP}) is a measure of thermal performance of heat pipe, which is defined as:

$$RHP = \frac{\Delta T}{Qout}$$, Where $\Delta T = T_e - T_c$



“Fig 4.3 Effect of the heat transfer rate on overall thermal resistance of heat pipe”

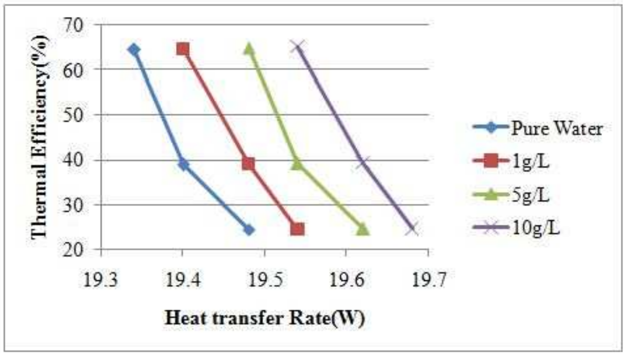
Fig. 4.3 shows the changes in the overall thermal resistance of the heat pipe for various heating power, as well as different fluid concentration values of CuO/Water nanofluid heat pipe

The figure shows that the overall thermal resistance of heat pipe decreases as concentration of nanofluid increases. The experimental result shows that the minimum value of overall thermal resistance is obtained 3.02 ⁰C/W, at 30W with 10 g/L nanofluid, which is 44.37 % less than that of pure water.

Effect of heat transfer rate on the overall thermal Efficiency of heat pipe:

The efficiency of heat pipe can be expressed as a ratio of the output heat by condensation to the inlet heat by evaporation, i.e.

$$\eta HP = \frac{Qout}{Qin}$$



“Fig. 4.4 Effect of heat transfer rate on the overall thermal Efficiency of heat pipe”

Fig. 4.4 shows the changes in the thermal efficiency of the heat pipe for various heating power, as well as different fluid concentration values of CuO/Water nanofluid heat pipe.

The figure shows that the thermal efficiency of heat pipe increases as concentration of nanofluid increases. The experimental result shows that the maximum value of thermal efficiency is obtained 65.14 at 30 W with 10 g/L nanofluid which is 62.62 % more as that of pure water.

Conclusions

Based on the analysis of the experimental investigations presented in this paper, the conclusions are as follows:

1. The thermal performance of nanofluids is influenced by alteration in the fluid-solid interface due to presence of nanoparicles.
2. The thermal resistance of the heat pipes decreases with the increase of concentration of nanofluid. The minimum value of overall

thermal resistance is obtained 3.02 ^{0}C/W 30W with 10 g/L nanofluid, which is 44.37 % less than that of pure water.

3. The heat transfer rate increases in case of the heat pipes with CuO nanoparticles as the increases concentration of nanofluid. The maximum value of heat transfer rate is obtained 19.68 W at 80 W with 10 g/L nanofluid which is 1.75 % more than that of pure water.
4. The thermal efficiency of the heat pipe increases with increasing nanoparticle concentration in the base fluid. The maximum value of thermal efficiency is obtained 65.14 at 30 W with 10 g/L nanofluid which is 62.62 % more than that of pure water.

References

[1] X.Wang, X.Xu, S.U.S.Choi, Thermal conductivity of nanoparticle–fluid mixture, Journal of Thermo physics and Heat Transfer 13(4) (1999) 474-480.

[2] S. Lee, S.U.S. Choi, S. Li, J.A. Eastman, Measuring thermal conductivity of fluids containing oxide nanoparticles, Journal of Heat Transfer 121 (1999) 280–289.

[3] Das, S.K.; Putra, N; Roetzel, W. Pool boiling characteristics of nanofluids, International Journal of Heat and Mass Transfer 46 (2003) 851– 862.

[4] S. Khandekar, Y.M. Joshi, B. Mehta, Thermal performance of closed Two-Phase Thermosyphon using nanofluids, International Journal of Thermal science. 47(2008) 659-667.

[5] S. W. Kang, W. C. Wei, S. H. Tsai, C. C. Huang, Experimental investigation of nanofluids on sintered heat pipe thermal performance, Applied Thermal Egg. 29(2009) 973-979.

[6] S.H. Noie, S.Z. Heris, M. Kahani, S. M. No wee. Heat transfer enhancement using Al_2O_3/ Water nanofluid in a Two-Phase Closed Thermosyphon. International Journal of Heat and Fluid Flow 30(2009) 700-705.

[7] P. Naphon, D. Thongkum, P. Assadamongkol. The heat pipe efficiency enhancement with refrigerant-nanoparticles mixtures. Energy Conversion and Management 50(2009) 772-776.

[8] Z. H. Liu, Y. Y. Li, R. Bio, Thermal performance of inclined grooved heat pipes using nanofluids, International Journal of Thermal Science. 49(2010) 1680-1687.

[9] M. Shafai, V. Bianco, K. Vafai, O. manca, An Investigation of the thermal performance of cylindrical heat pipes using nanofluids. International journal of Heat and Mass Transfer 53(2010) 376-383.

[10] Y. Ji, H. Ma, F. Su, G. Wang, Particle size effect on heat transfer performance in an oscillating heat pipe, Exp. Therm. Fluid Sci. 35 (2011) 724–727.

[11] G. Huminic and A. Huminic, Heat transfer characteristics of a Two-Phase Closed Thermosyphons using nanofluids. Experimental Thermal and Fluid science 35(2011) 550-557.

[12] G. Huminic, A. Huminic, I. Morjan, F. Dumitrache, Experimental study of the Thermal performance of thermosyphon heat pipe using Iron oxide nanoparticles. International Journal of Heat and Mass transfer 54 (2011) 656-661.

[13] Jian Que, Huiying Wu, Thermal performance comparison of oscillating heat pipes with SiO_2/Water and Al_2O_3/Water nanofluids. International Journal of Thermal science 50(2011) 1954-1962.

[14] A. B. Solomon, K. Ramachandran, B. C. Pillai, Thermal performance of a Heat pipe with nanoparticles coated wick. Applied Thermal Engineering 36 (2012) 106-112.

[15] K. Alizad, K. Vafai, M. M. Shafahi, Thermal performance and operational attributes of the start-up characteristics of flat-shaped heat pipes using nanofluids. International journal of Heat and Mass Transfer 55(2012) 140-155.

[16] R. Hajian, M. Layeghi, K. A. sani, Experimental study of nanofluid effects on the thermal performance with response time of heat pipe, Energy Conversion Management 56 (2012) 63-68.

[17] Yi-Husain Hung, Tun- Ping Teng, Bo-Gu Lin, Evaluation of thermal performance of a heat pipe using alumina nanofluids. Experimental Thermal and Fluid Science 44(2013) 504-511.

[18] Rosari Saleh, Nandy Putra, Suhendro Purbo Prakoso, Wayan Nata Septiadi, Experimental investigation of thermal conductivity and heat pipe thermal performance of ZnO nanofluids. International Journal of Thermal Sciences 63 (2013) 125-132.