ENHANCEMENT OF THERMAL PERFORMANCE OF NANOFLUIDS IN HEAT PIPE

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ABSTRACT

The using of nanofluid as a perfect choice to replace convectional fluids is the most promising technique that used for enhancement thermal performance for heat transfer process. The effect of nanofluids Alumina-deionized water (DI) (Al_2O_3-H_2O) with wick in the heat pipe for enhancement the heat pipe thermal performance has been investigated experimentally in this work. The heat pipe contain two phases vapor phase in lower part from the heat pipe and liquid phase in upper part from the heat pipe, using three concentration of nanofluid (ϕ =0%,0.05%,0.1%) ,three value of heat flux (7.4W,11W,16.8W) and two value of angle of heat pipe (90^o,45^o). Result showed decrease the time to reach the steady state when increases the concentration of nanofluid ,heat flux and incline the heat pipe from 90^o angle to 45^o angle . The properties such as viscosity, density and thermal conductivity for nanofluid increase when the concentration of nanofluid increase, the heat pipe thermal performance is enhancement by increasing of nanofluid concentration, heat flux and incline the heat pipe from 90^o angle to 45^o angle.

KEYWORD: *Heat pipe, Nanofluid, deionized water (DI), Alumina, Properties of nanofluid, Time of steady state.*

I. INTRODUCTION

A device that is used to transfer thermal energy between two or more fluids is a heat exchanger; its transfer is between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. There are usually no external heat and work interactions in heat exchanger. The perfect applications involve is heating or cooling of a fluid stream of concern and evaporation or condensation of single- or multicomponent fluid stream [1]. The heat exchangers common examples are automobile radiators, shell-and tube exchangers, condensers, air preheaters, evaporators, and cooling towers. It is sometimes referred to as a sensible heat exchanger if no phase change occurs in any of the fluids in the exchanger. There are internal thermal energy sources in the exchangers, such as in nuclear fuel elements and electric heaters [1]. Effective heat transfer devices with an intermediate heat medium phase transformation in a closed cycle (evacuated tube) are heat pipe. The two phases: condensation and evaporation are used to transfer the heat supplied e.g. from a processor. Due to their ability heat pipe are used to achieve high thermal conductance in steady state operations [2]. A working fluid for cooling purposes include engine oil, water and ethylene glycol have been utilized. These fluids have thermal conductivity lower than metals and ionic components such as: copper, silicon carbide and copper oxide. Maxwell initiated the characteristics of these metals and ionic components gave rise to a fluid that consisted of a mixture of a metals and base fluid. One of the most important parameters in a working fluid that led to the improvement from this idea of a suspension: thermal conductivity [3] .The heat pipe concept was originally proposed by King and Perkins during mid 18th century in the United Kingdom. Perkins tubes differ from present day heat pipe in the sense that they do not have a wick structure and are gravity assisted. Y.H Lin et al., [4] investigated the performance of heat pipe with silver water nanofluid. P Naphon et al., [5] performed experiment with water alcohol and nanofluid (alcohol+nanoparticle) (TiO2 21nm). Z H Liu et al., [6] conducted study with nanoparticle CuO, Cu and SiO with DI water as base fluid. Shafahi et al., [7] were study thermal performance of rectangular and disc shaped heat pipe with nanofluid. Sameer K et al., [8] conducted a review on methodologies to predict hydrodynamic properties of uni-directional two-phase Taylor bubble flow. M G Mousa [9] conducted experiment with pure water and Al2O3-water based nanofluid in heat pipe. Y H Hung et al., [10] investigated performance of heat pipe with Al_2O_3-water nanofluid (0.5, 1, 3 wt %). Shafahi et al.,[11] studied thermal performance of rectangular and disc shaped heat pipe with nanofluid. Author reports a substantial increase in thermal performance of flat shaped heat pipe. Y H Hung et al.,[12] investigated performance of heat pipe with Al2O3-water nanofluid (0.5, 1, 3 wt %). Chitosan 0.2% was used as dispersant in this experiment. The optimum filling ratio was at 20-40% range. Tilt angle for maximum performance was 40-700. L.G Asirvatham et al.,[13] investigated the performance of heat pipe with silver nanofluid in D.I water.

This research was done by Shahad Falih Hassan in Electrochemical Engineering Department in Babylon University.

II. EXPERIMENTAL SETUP

Fig.(1) shows the experimental setup configuration schematic and consideration .The apparatus used in this experimental consists of the heat pipe, cooling system, heater, data logger, power supply, ammeter. The heat pipe is constructed from glass and contain wick inside it. The dimensions of it are (43 cm) length (included heater and condenser).The top part of heat pipe is condenser and its dimensions are (6 cm) length, (10 mm) outside diameter, (7 mm) inside diameter. The bottom part of heat pipe is heater and its dimensions are (7 cm) length, (27 mm) outside diameter, (25 mm) inside diameter. By put (12.5 ml) of solution (deionized water (DI)-Al_2O_3) in heater part the solution will boiling and the vapor will rise to the top part (condenser),then the vapor will condensate on the wall of heat pipe going bag to the heater. The material of wick is cupper tube and its covered by plastic mish shown in fig.(2). Table (1) shows design parameters of heat pipe. Shown in table (2) properties of (Al_2O_3) nanaparticles, and physical properties of deionized water (DI) show in table (3).

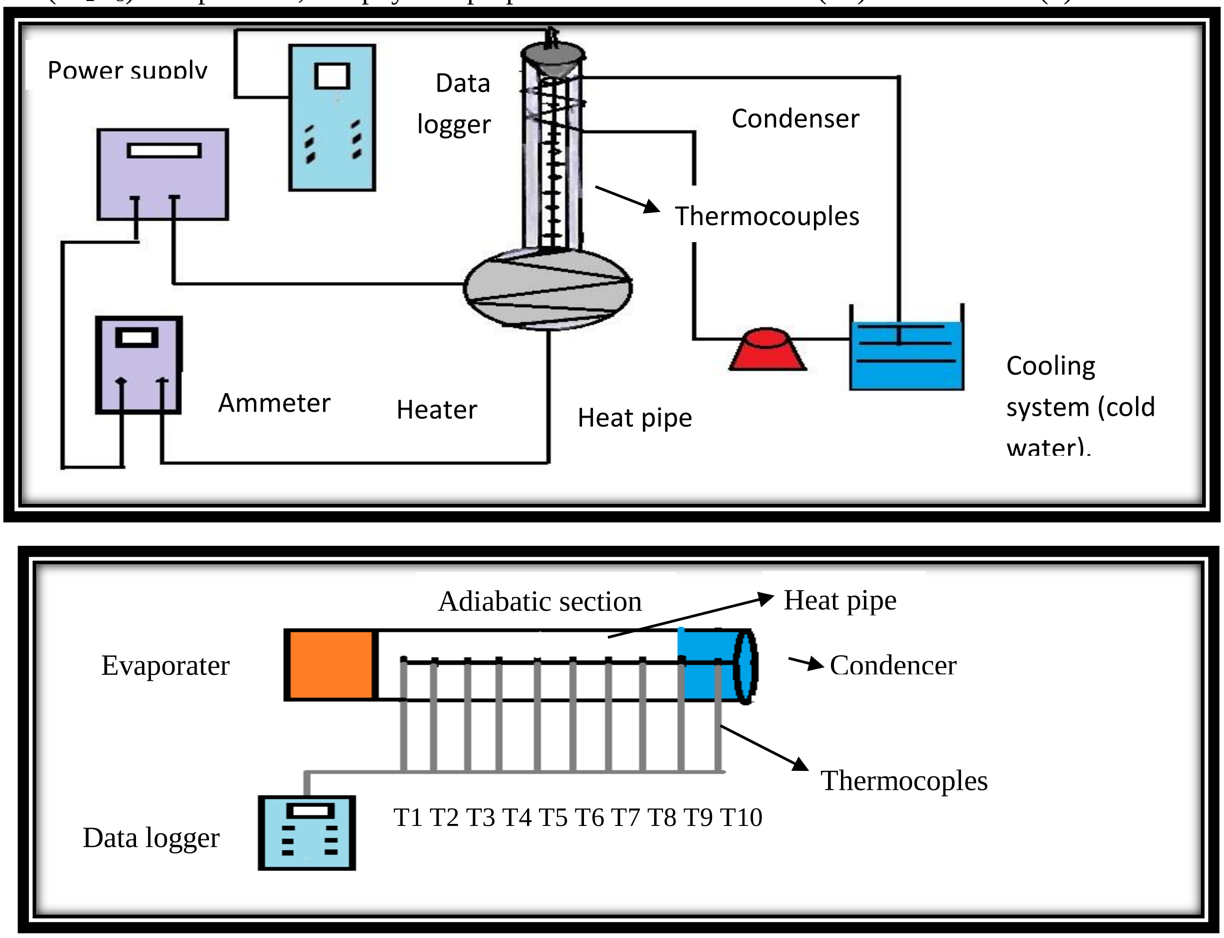


Fig.(1): The Schematic of Experiment Setup.

Fig .(2): The wick type in heat pipe

Table (1): Main design parameters of heat pipe .

Parameter	Value
Heat pipe material	Gless
Heat pipe length	43 cm
Heat pipe ID/OD	7-10 mm
Wick material	Copper
Wick length	34 cm
Wick ID/OD	4.5-5.4 mm
Heater length	7 cm
Heater ID/OD	25-27 mm
Cndenser length	6 cm
Amount was added to heater from nanofluid.	12 ml

Table (2): (Al_2O_3) nanaparticles properties .

Property	Al_2O_3 nanoparticles
Thermal conductivity	40 W/mK
Specific heat	0.775 J/g.K
Density	3890 Kg/m3
Specific suface	15-20 m2/g
Thermal expansion coefficient	5.4 . 10^-6 m/m.k
Enthalpy from 25^{o}c	0 J/g
Shear modulus	164-140 GPa
Hardness HV1.0	1500-2000

Table (3): Physical Properties of deionized water (DI)

Property	deionized water(DI)
Melting point	0^o C
Boiling point	100.2^o C
Molar mass	18.01528 g/mol
Vaper pressuer at (25^{o}c)	0.031276 atm
Thermal Conductivity	0.6067 W/m.k
Density	999.972 Kg/m3
Viscosity at (25^{o}c)	0.89 cp
Acidity (PKa) at (25^{o}c)	13.995
Basicity (PKb) at(25^{o}c)	13.995
Specific heat capacity	75.375 -+ 0.05 j/mol.k
Gibbs free energy	-237.24 Kj/mol

III. NANOFLUID EFFECTIVE PROPERTIES

The heat transfer effectiveness is shown by the convective heat transfer coefficient, which is a function of a number of the nanofluid thermo- physical properties, the most significant ones being specific heat, density, thermal conductivity and viscosity [14].
The nanofluid density

$$\rho_n = \rho_s \phi + \rho_f (1 - \phi) \tag{1}$$

The nanofluid heat capacity

$$Cp_n = (\rho_s Cp_s \phi + \rho_f Cp_f(1-\phi))/\rho_n \tag{2}$$

The nanofluid viscosity

$$\mu_n = \frac{\mu_f}{(1-\phi)^{2.5}} \tag{3}$$

*T*he nanofluid thermal conductivity

$$\frac{k_n}{k_f} = \frac{k_p + 2k_f - 2(k_f - k_p)\phi}{k_p + 2k_f + (k_f - k_p)\phi} \tag{4}$$

IV. EXPERIMENTAL PROCEDURE OF NANOFLUID

The nanofluid that we used for the experiments has different volume fraction (ϕ = 0, 0.05, and 0.1). The nanofluid is put in heater part of heat pipe with amount 12.5ml .The data logger is set and switched on .The readings of thermocouple recorded each one second and saved in Temperature Recorder (data logger) by SD-RAM .Their reading were observed with time until it became constant, at that time data logger was switched off and SD-RAM was drown.

V. THE EXPERIMENTAL RESULTS

A practical study of heat transfer analysis out to investigate the effect of the addition of nanoparticles (Al_2O_3) to the base fluid deionized water (DI) on the heat pipe performance. The upper part of the heat pipe was subjected to a cooling system. Where the lower part was subjected to a heating system. Ten K-type thermocouples were used to measure and then recorded the change in temperature with time .As discussed earlier in chapter three, three different values of solid nanoparticles concentration were used (0.0, 0.05, 0.1vol/vol); three different values of power were used (7.4w,11w, 16.8w) and two different values of angle were used (90^o, 45^o) in the experiments .

Table (4): Summaries the number and the type at experiment in system work.

Model	ϕ (%)	Heat flux (W)	θ (^{o})
1	0	7.4w	90^o
	0.05	11w	45^o
	0.1	16.8w	

5.1. *Transient state*

The heat pipe response time is an appropriate characteristic to study its performance and transient behavior. The definition of the response time of heat pipe is based on the variation of surface temperature of heat pipe.

Fig (3) shows the typical temperature profile in the heat pipe for model no. 1 with heat flux of power (16.8 w) and vertical position filled with pure DI water (ϕ =0), the figure represent the temperature study for tow section lines of heat pipe, the vapor and the liquid section .Lines T1 –T5, refer to vapor section whereas the lines T6 –T10 refer to liquid line. As shown in the figure, the temperature of the liquid section increase gradually until reach the steady state temperatures in the range of (‿35 ^{o}C) of the (40) minutes .Whereas the temperature of the vapor increase rapidly and reach the temperature of (‿100^{o}C) of the (44)minutes. This figure represents the general thermal behavior in the heat pipe under variety of heat flux and nanoparticals of different inclined angle.

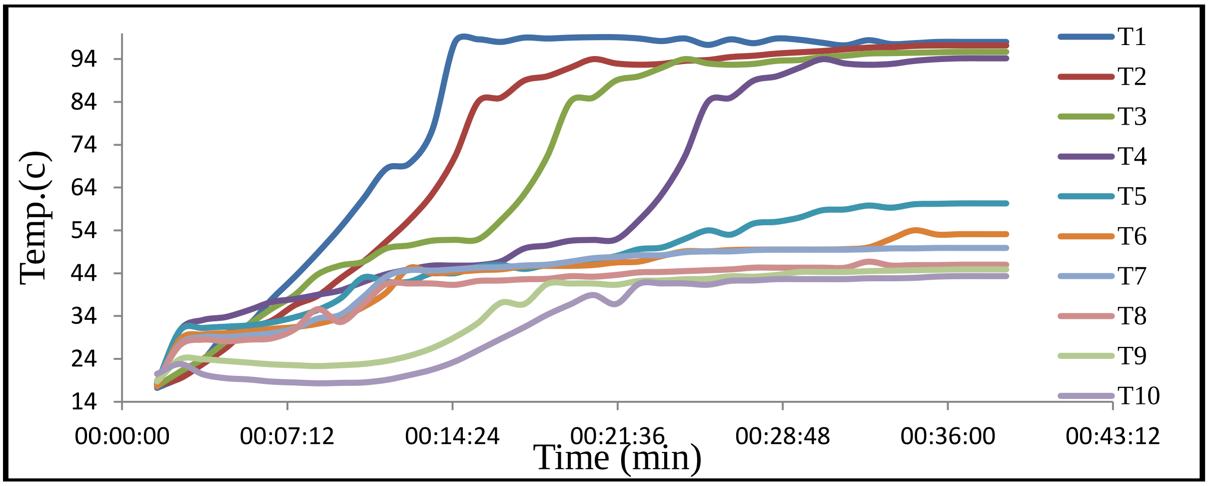


Fig. (3): Temperature v.s time (power=16.8W,angle=90°,ϕ=0).

5.1.1. Concentration effect

To explain the behavior of concentration of nanofluids in a heat pipe, fig.(4) show the thermal behavior on temperature profile in the heat pipe for different values of nanofluid concentration .as shown the fig.(4) the time required to reach the steady state decrease when the concentration of nanofluid (Three values 0, 0.05, 0.1) increase for both liquid side and vapor side.

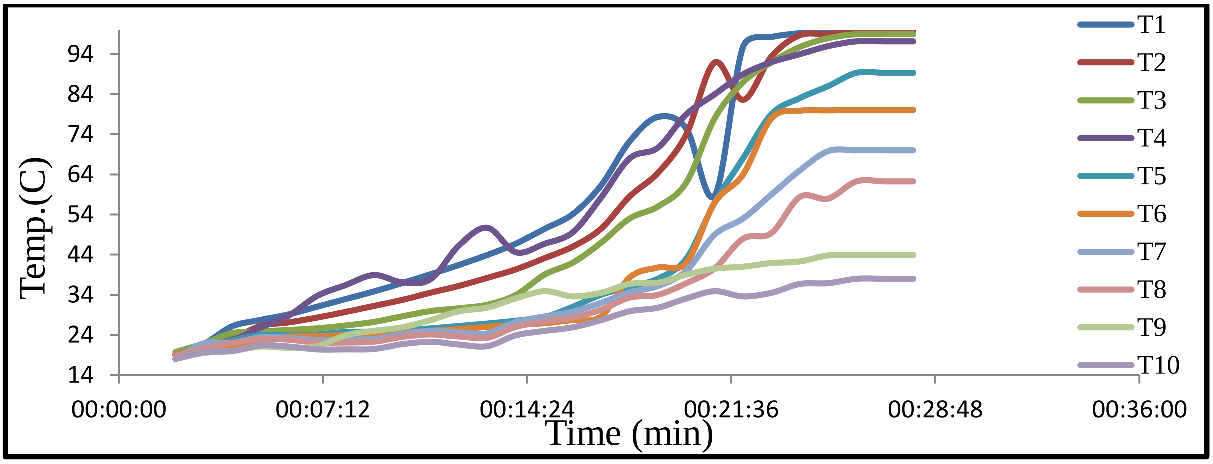


Fig .(4): Temperature v.s time (power=11W,angle=90°,ϕ=0.1).

Fig.(5) show the comparison by time between three different concentration of nanofluid in three point of thermocouples (T1,T2,T3) in heat pipe for (11W) heat flux and vertical heat pipe.

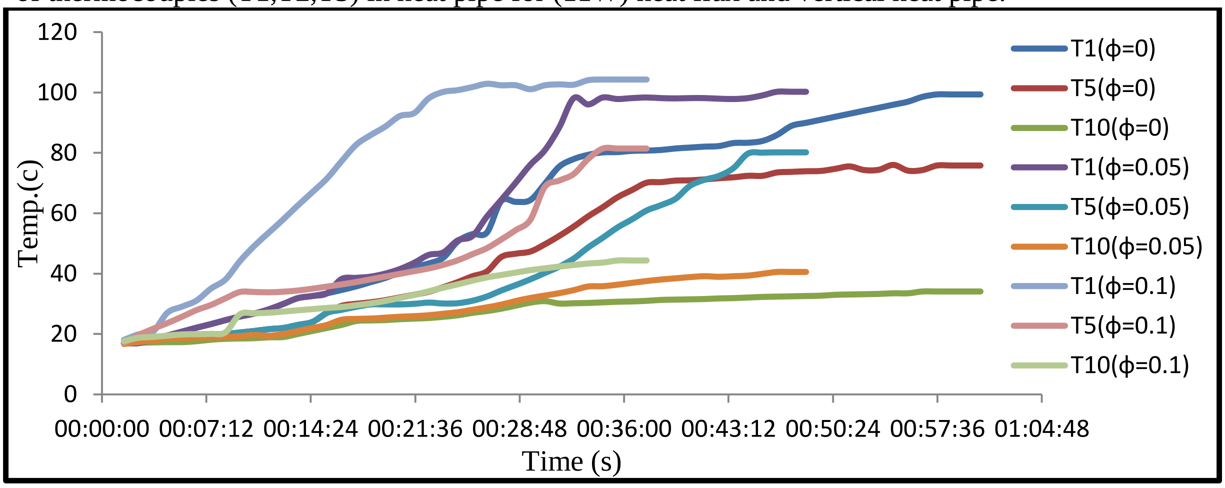


Fig .(5): Temperature v.s time (power=11, angle=90°) with different concentration of nanofluid.

5.1.2. Heat flux effect

The temperature gradient along the heat pipe axis increases with increase in heat flux.

Fig.(6) show the thermal behavior on temperature profile in the heat pipe for different values of heat flux .as shown the fig.(6) the time required to reach the steady state decrease when the heat flux three values of heat flux 7.4W,11W,16.8W)increase for both liquid side and vapor side.

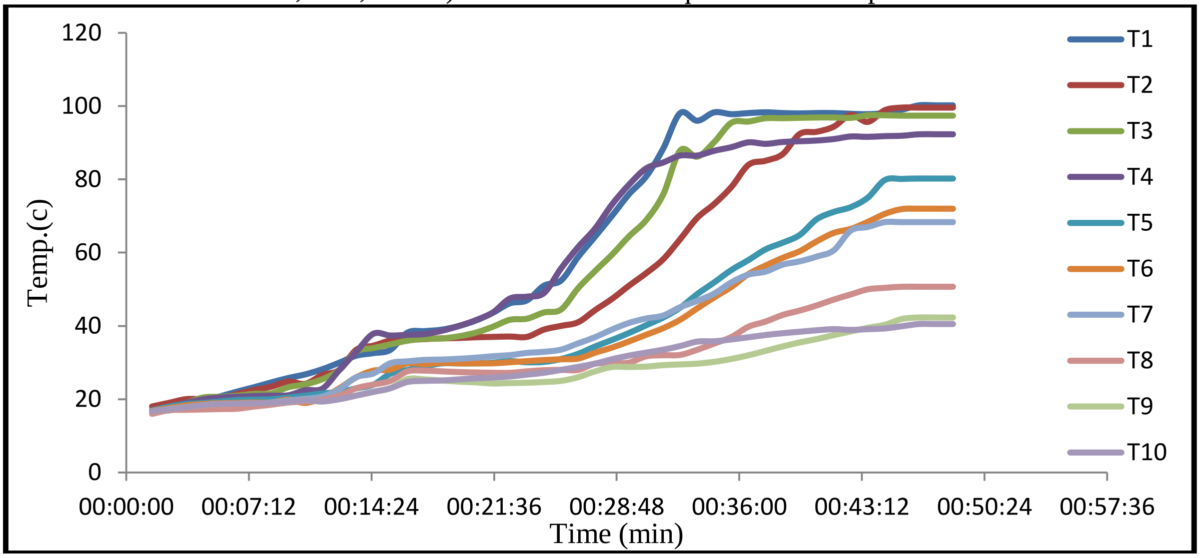


Fig.(6): Temperature v.s time (power=11W,angle=90°, ϕ=0.05).

Fig.(7) show the comparison by time between three different heat flux in three point of thermocouples (T1,T2,T3) in heat pipe for (0.05) concentration of nanofluid and vertical heat pipe.

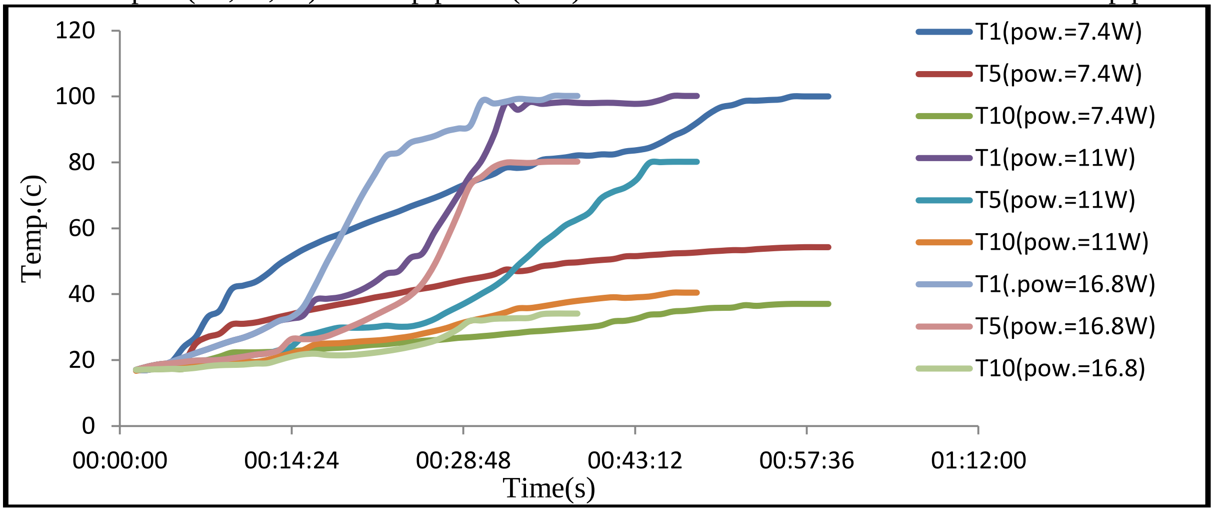


Fig .(7): Temperature v.s time (ϕ=0.05%, angle=90°) with different power.

5.1.3 Angle effect:

Heat transfer increases when angle was inclination, as from vertical (90°) to (45°). Fig.(8) show the thermal behavior on temperature profile in the heat pipe for different values of angle .as shown the fig.(8) the time required to reach the steady state decrease when the angle two values of angle 90°,45°) inclination for both liquid side and vapor side.

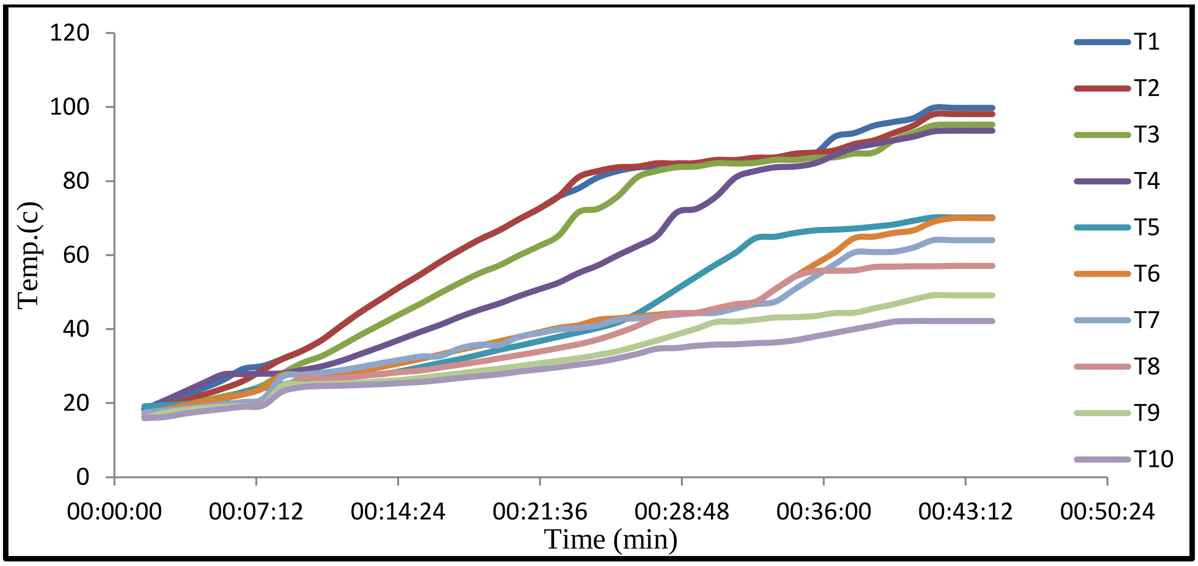


Fig .(8): Temperature v.s time (ϕ=0.05%, power=16.8W, angle=45^o).

Fig.(9) show the comparison by time between two different angle in three point of thermocouples (T1,T2,T3) in heat pipe for (0.05) concentration of nanofluid and(16.8W)heat flux.

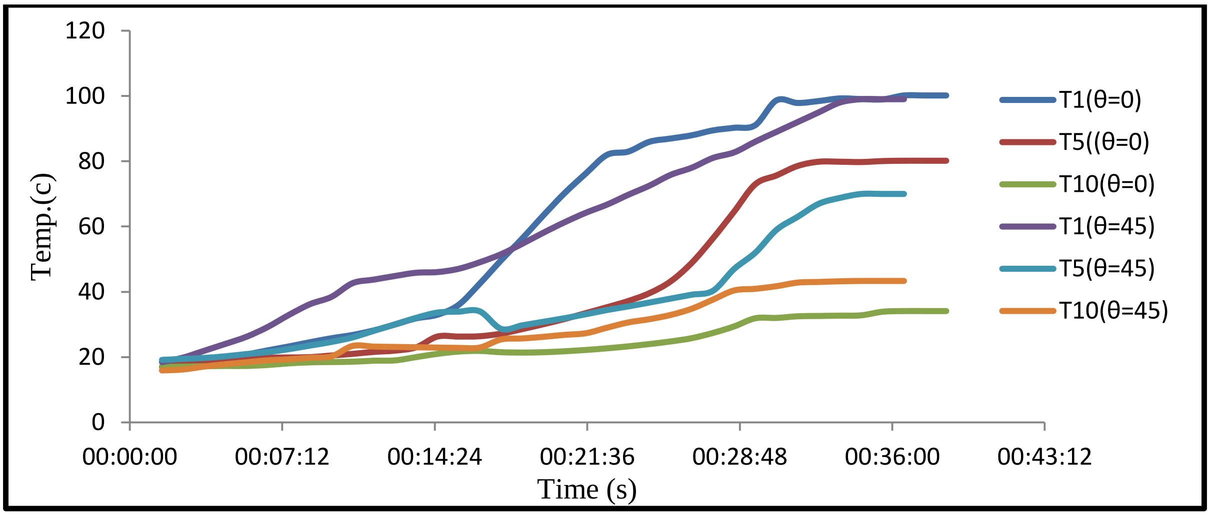


Fig .(9): Temperature v.s time (ϕ=0.05%, power=16.8w) with different angle.

5.2. Steady state temperature distribution:

In this part the temperature distribution in the heat pipe at the both side liquid phase and vapor phase are shown and discussions depending on the effect of nanoparticles concentration, heat flux ,inclination angle for different models of the wick that constructed in this work. The drawing temperatures values in steady state (recent values) opposite distance (z) of thermocouples in heat pipe with different concentration of nanoparticles, to be gauged effect concentration of nanofluid on enhancement of heat transfer. Fig.(10) show the steady state temperature distribution for both side liquid phase and vapor phase in heat pipe located vertically (θ=90^o) for different volume of nanoparticles concentration and heat flux .It is found that the temperature in both side for nanofluid were always higher than for base fluid and increase when the concentration increase. This is due to reduce the thermal measurement of the fluid .Moreover the increase in heat flux of the hot part of the heat pipe will always increase the temperature in heat pipe.and temperatures distribution in heat pipe will became improve .Fig.(11) show the steady state temperature distribution for both side liquid phase and vapor phase in heat pipe located in angle (45°). The temperature distribution through the heat pipe for angle (45°) will be better than from angle (90°).

[1]: heat flux = 7.4W

[2]: heat flux= 11W

[3]: heat flux= 16.8W

Liquid phase Vapor phase

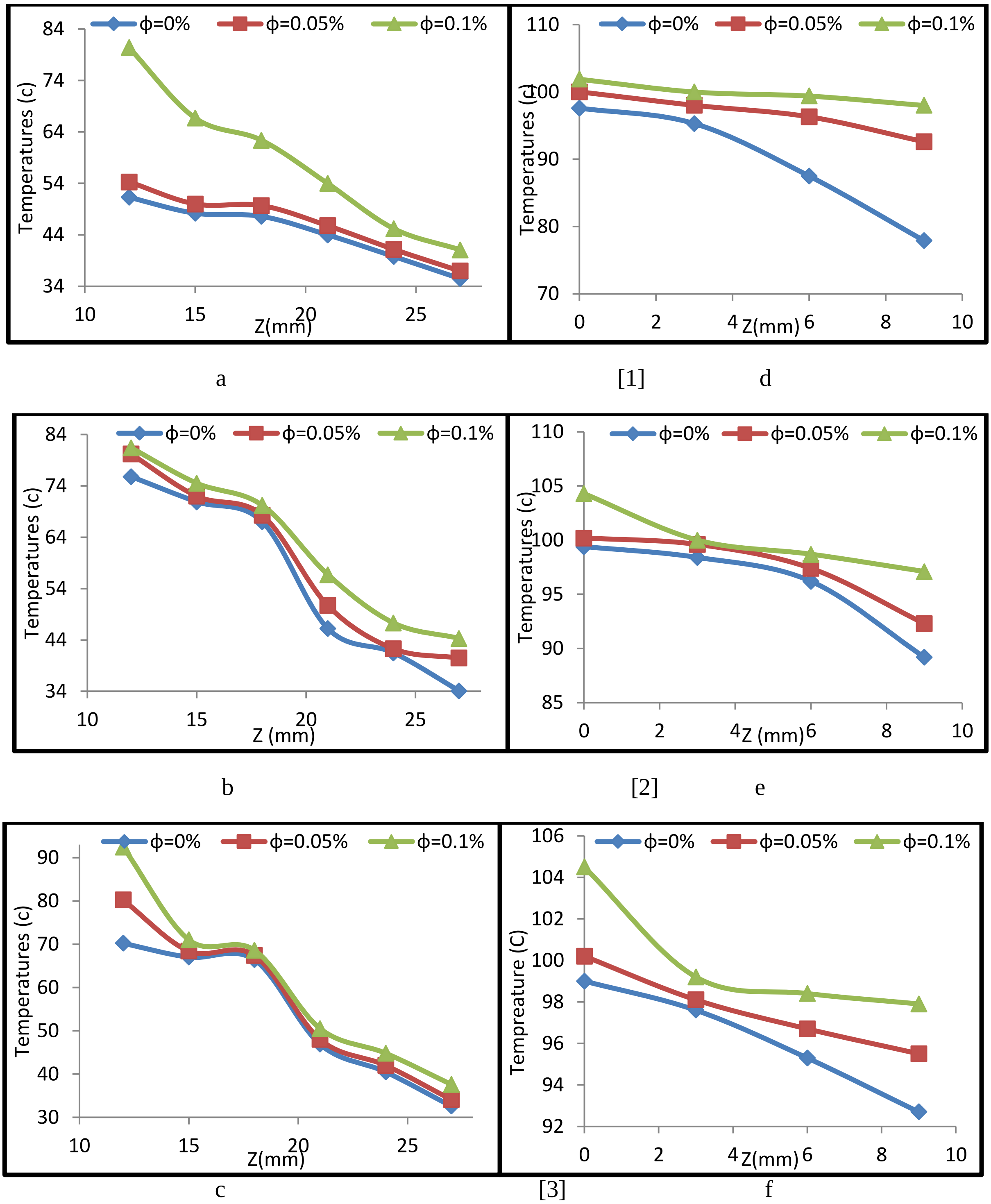
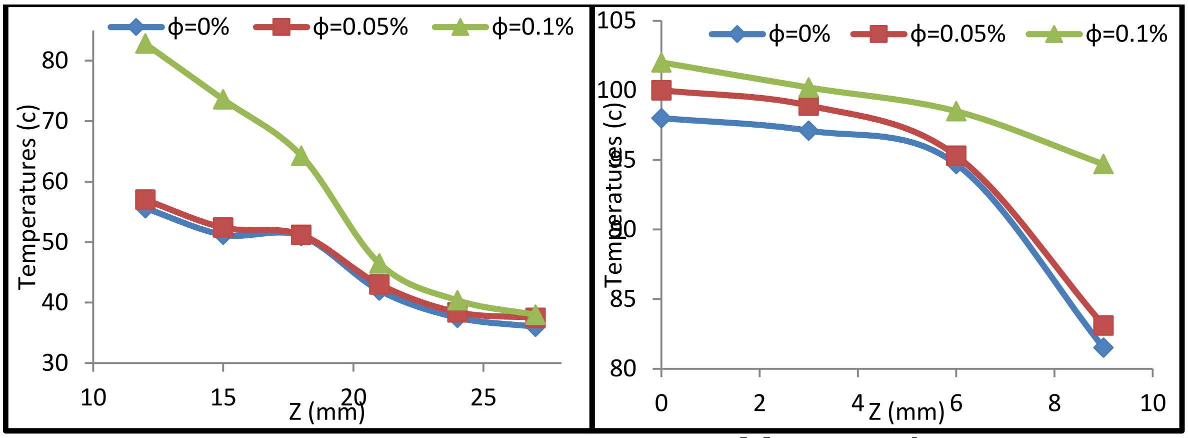
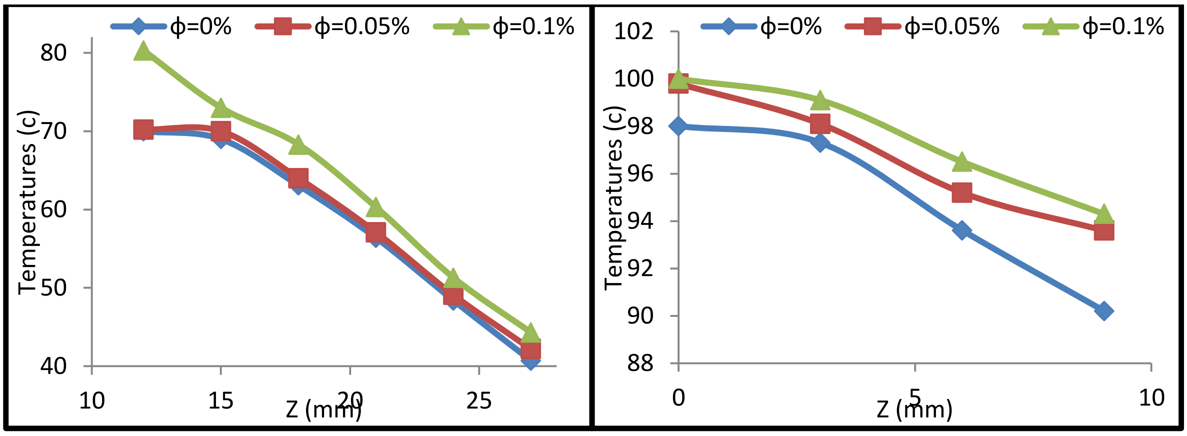


Fig.(10): Effect of heat flux for different value of concentration for both side liquid phase and vapor phase in angle (90°).

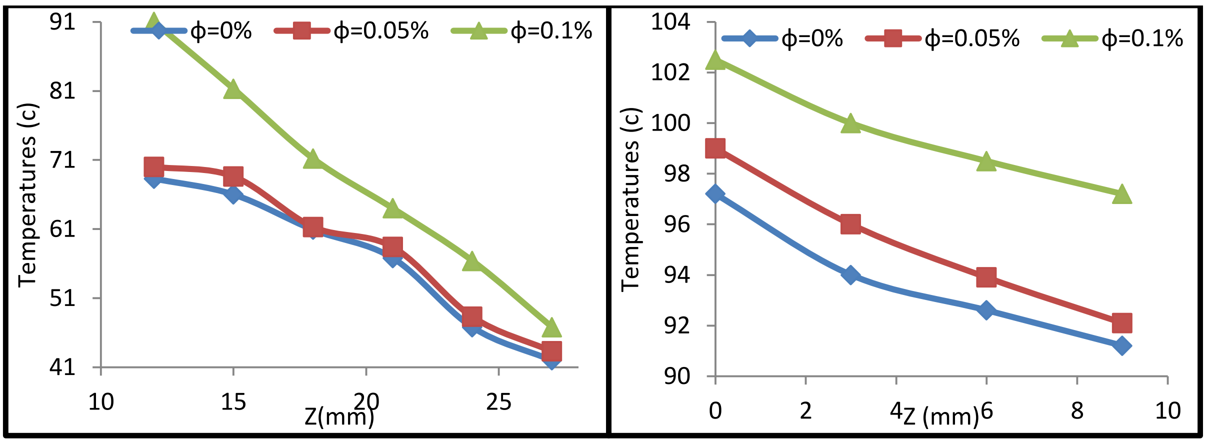
Liquid phase Vapor phase



a [1] d



b [2] e



c [3] f

Fig.(11): Effect of heat flux for different value of concentration for both side liquid phase and vapor phase in angle (45°).

5.3. Time of the steady state

The time will be decrease in all models when the heat flux and concentration of nanofluid increase for vertically heat pipe ,but by changing the degree of angle to 45° the decreasing of the time to reach the steady state will be more than the vertical angle of heat pipe.Fig .(12) shows that for concentration of nanofluid (ϕ =0) the time decreasing percent between heat flux from (7.4W-11W) is (36.84%)and from (11W-16.8W) is (16.66%). For concentration of nanofluid (ϕ =0.05) the time decreasing percent between heat flux from (7.4W-11W) is (18.64%) and from (11W-16.8W) is (20.83%) .For concentration of nanofluid (ϕ =0.1) the time decreasing percent between heat flux from (7.4W-11W) is (22.91%) and from (11W-16.8W) is (24.32%) to vertically heat pipe. Fig.(13) shows that for concentration of nanofluid (ϕ =0) the time decreasing percent between heat flux from (7.4W-11W) is (16.66%) and from (11W-16.8W) is (18.18%). For concentration of nanofluid (ϕ =0.05) the time decreasing percent between heat flux from (7.4W-11W) is (20%) and from (11W-16.8W) is (20.45%). For concentration of nanofluid (ϕ =0.1) the time decreasing percent between heat flux from (7.4W-11W) is (25%) and from (11W-16.8W) is (16.66%) to 45° angle of heat pipe.

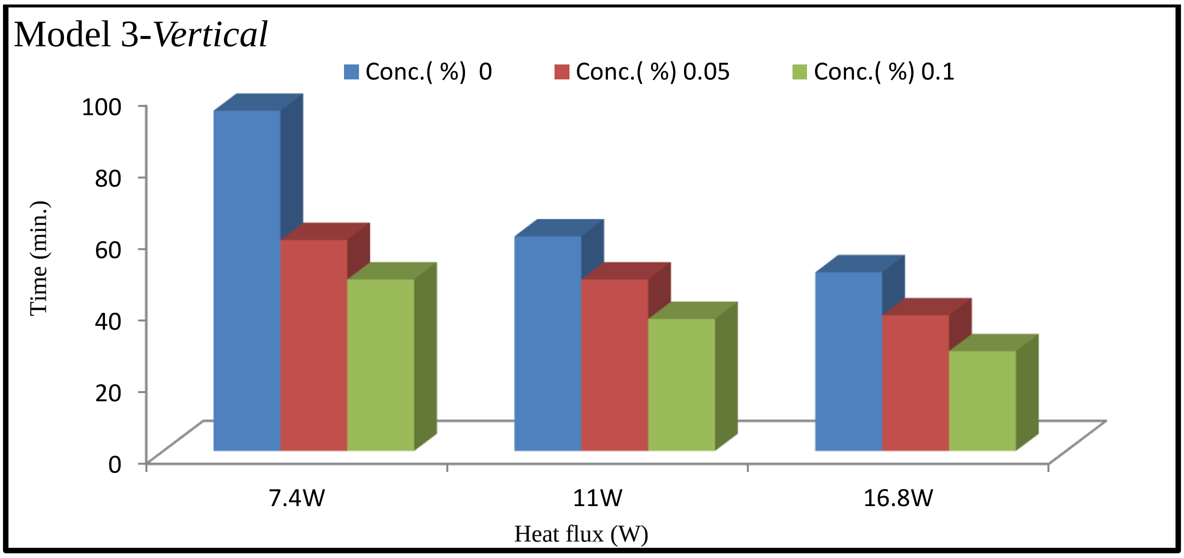


Fig.(12): Time v.s heat flux in angle 90°.

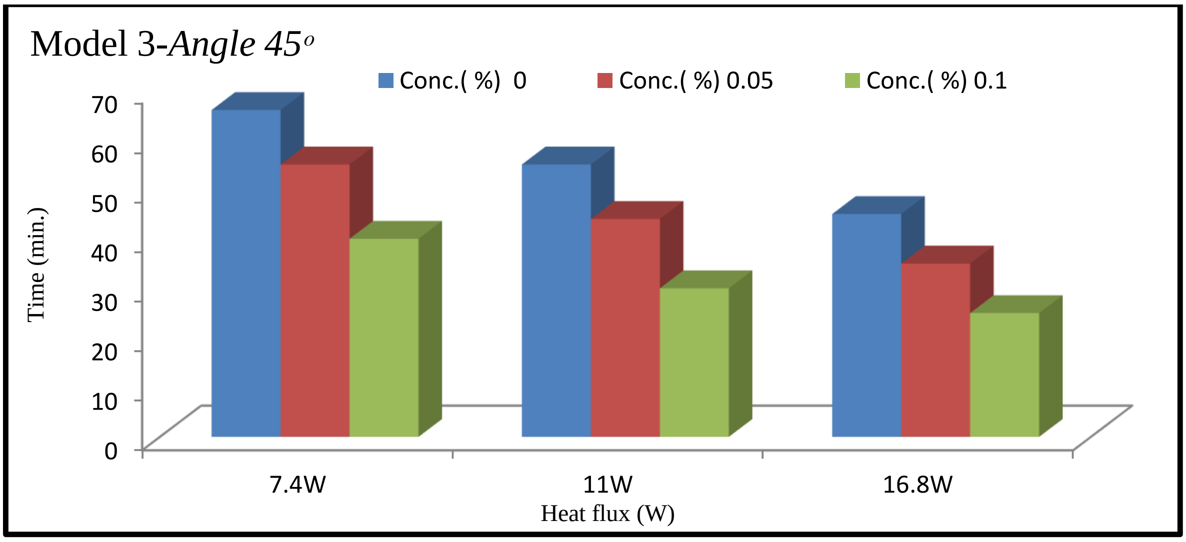


Fig.(13): Time v.s heat flux in angle 45°.

5.4. Performance of heat pipe

Performance in the heat pipe represented by decreases in the time to reach the steady state. This decreases due to increase the concentration of nanofluid and heat flux. The performance is calculated by the following equation:

$$\text{Performace} = \frac{t_{sswn} - t_{sspure}}{t_{sspure}} \times 100\,\% \qquad (4.1)$$

t_{sswn} = Steady state time with nanoparticles.

t_{sspure} = Steady state time with deionized water (DI) .

Table (5) and (6) shows the value of performance for two different type of heat pipe vertical and angle 45°.This percent show when increases concentration of nanofluid the performance will be enhancement, also when increase the heat flux the performance will be enhancement at same angle.

Table (5): The performance of vertical heat pipe for two concentrations.

Concentrations	7.4W	11W	16.8W
ϕ=0.05%	34%	35.71%	36.66%
ϕ=0.1%	46.6%	47.14%	53.33%

Table (6): The performance of angle 45° heat pipe for two concentration.

Concentrations	7.4W	11W	16.8W
ϕ=0.05%	16.6%	20%	22.22%
ϕ=0.1%	39.39%	40%	44.4%

Fig. (14) and(15) shows the present increases of performance of heat transfer at different concentration of nanofluid and heat flux.

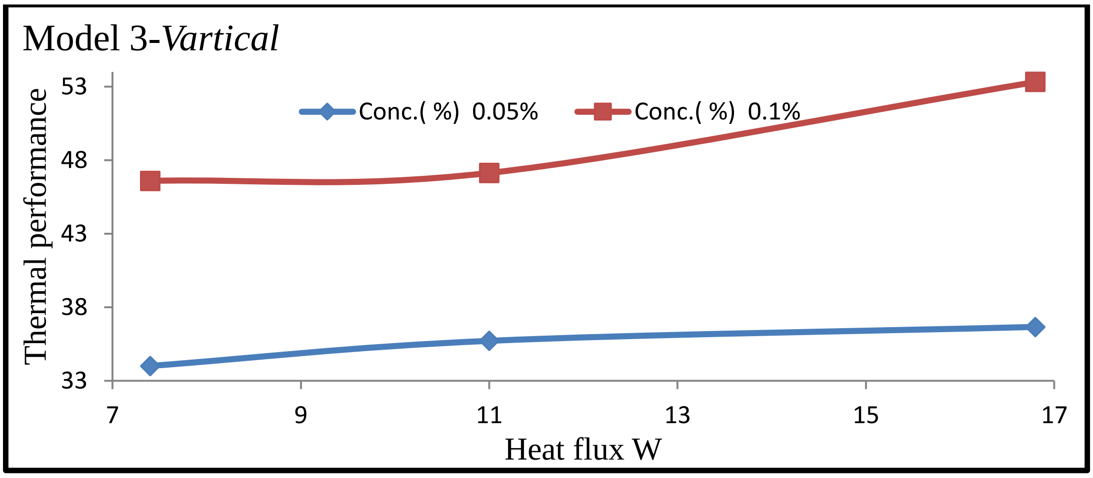


Fig. (14): Performance of heat pipe v.s heat flux in vertical heat pipe.

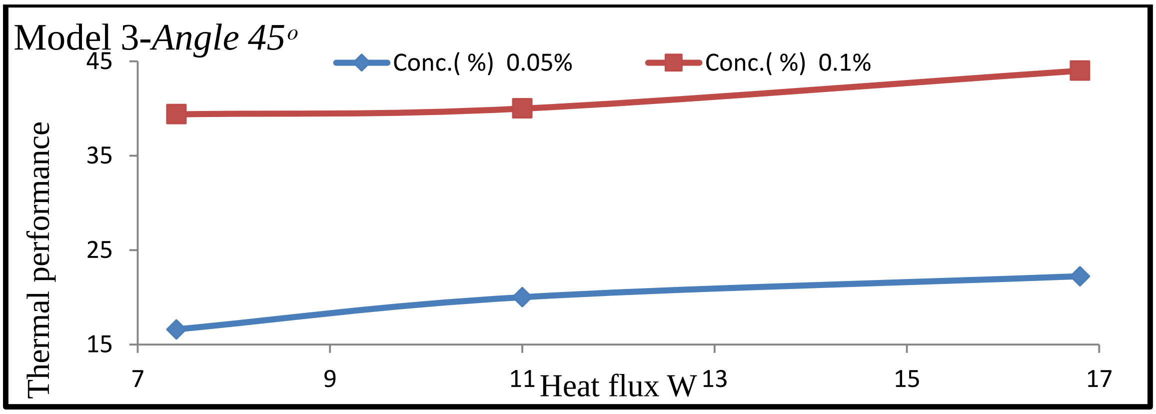


Fig. (15): Performance of heat pipe v.s heat flux in angle 45° heat pipe.

VI. CONCLUSIONS

1. The Heat transfer enhancement increases with increase nanoparticles (Al2O3) volume fraction, power and inclination angle of heat pipe.
2. In transient state the time to reach steady state decrease when increase nanoparticles (Al2O3) volume fraction, power and inclination angle of heat pipe.
3. Heat pipe will consists of two phase vapor phase at below region from heat pipe (four thermocouples) and liquid phase at top region from heat pipe (six thermocouples).
4. The temperatures is decrease in heat pipe when increase distance (z) gradually (at heater z=0).
5. In steady state when increase nanoparticles (Al2O3) volume fraction at same distance (z) the temperatures increase.
6. Thermal conductivity (k), density (ρ) and viscosity (μ) increase when the volume fraction of nanoparticles increased.
7. Thermal performance is enhancement by increasing concentration of nanofluid and heat flux and incline angle from 90^{o} to 45^{o} degrees.

VII. RECOMMENDATIONS

1. Studying the heat transfer enhancement of the other types of the heat exchanger.
2. An experimental study can be done with the other types of heat pipe.
3. Using another types of the nanoparticles.
4. An experimental study can be carried out used with more values of power and angle in the heat pipe.
5. Studying the heat transfer enhancement in of the other types of wick in the heat pipe.
6. A similar study that focuses on the use of other models of the heat pipe.

NOTATION

k_f : Thermal conductivity of fluid (W/m. °C)
k_n : Thermal conductivity of nanopartical (W/m. °C)
Cp : Heat capacity (J/Kg.K)
k_b : Boltzmann constant (m^2kg $s^{-2}K^{-1}$)
T : Time (min)
ρ: Fluid density (g/cm^3)
ϕ: Volume fraction
μ : dynamic viscosity (cp)

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