Experimental Study of Heat Transfer Characteristics by cooling Heat Pipe using Al_2O_3-Water Nanofluid

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Abstract – *The aim of this research is to investigate the viability of using nanofluid as an alternative as heat transfer fluid especially for cooling purposes in compact electronic equipments. In this study, nanofluid flow rate is varied to study the thermal performance characteristics. Al_2O_3-water base nanofluid is tested through the condenser side of sintered copper heat pipe. The Al_2O_3 nanoparticle is of 99% purity with particle size of 10nm. The evaporator side hot water is passed at variable mass flow rate. The sintered copper wick carries heat from evaporator side to condenser side by capillary action. The results obtained from this analysis concluded that nanofluid have better enchancement characteristics when compared with plain water for variable mass flow rate.*

Keywords* – *Heat pipes, Nanofluids, Overall Heat transfer co-efficient, Effectiveness, Resistivity, Flowrate.

1. INTRODUCTION

With ever-increasing energy demand, industries all over world are facing formidable challenges in meeting its energy needs and sustainable development. Energy conservation through energy efficiency measures shall play an important part to address these challenges to a large extent. To curb these challenges, researches are focused on working out energy efficient heat transfer fluids. In many industrial applications, the conventional heat transfer fluids are refrigerants, water, engine oil, ethylene glycol etc. Despite considerable research and development for improving energy efficiency and enhancing heat transfer characteristics, the cooling capabilities have been constrained because of poor thermal conductivities of heat transfer fluids. Improving the thermal conductivity is the key idea in enhancing the heat transfer characteristics of conventional fluids and in turn the heat transfer coefficient [1-10].

In electronic units like computers, electric home appliances, mobiles, smart phones etc, due to prolonged usage the heat generating within the device is enormous. It has become a major concern to reduce and to control these heat generation by all means. For such small size appliances, designing for a compact heat transfer device has become a new field of development for researchers. Devices operating at such high rate of heat generation result in damage of component and in some cases human lives. So, it has become an important factor to control the thermal characteristics and to provide consumers a safe and reliable devices. One of the many research in this field is to combine nanofluids with heat pipe and to study their heat transfer characteristics. Many researchers have found that nanofluid when combined with heat pipe gave enhanced results compared to other cooling fluids.

Heat pipes are used in several applications, where one has limited space and the necessity of a high heat flux. It is used in space applications as well as it is used in heat transfer systems, cooling of computers, cell phones and cooling of solar collectors. They constitute an efficient, compact tool to dissipate substantial amount of heat from various engineering systems including electronic components. Heat pipes are capable to dissipate substantial amount of heat with a relatively small temperature drop along the heat pipe while providing a self-pumping ability due to an embedded porous material in their structure. A limiting factor for the heat transfer capability of a heat pipe is related to the working fluid transport properties. In order to overcome this limitation, the thermo physical properties of the fluid can be improved [2]

Table 1: Summary of research on Al_2O_3-Water based nanofluid

Author (Year)	Working Fluid	Particle Size	Enchancement Achieved
Dae-Hwang Yoo et al., (2007)	Al_2O_3-Water	50nm	Enhanced thermal conductivity
Mousa M G (2011)	Al_2O_3-Water	40nm	Enhanced thermal performance by nanofluid.
Fei Duan et al., (2011)	Al_2O_3-Water	25nm	Enhanced relative viscosity
Kamaldeep	Al_2O_3-Water	20nm	Enhanced

et al., (2013)			thermal conductivity
A Sivakumar (2014)	Al_2O_3 with water as basefluid,	15nm	Enhanced thermal performance of Nanofluids than water.
R. Reji Kumar (2014)	Al_2O_3 with 0.1% mass concentration,	50nm	Variation in performance due to change in angle of inclination.
Kamble D P (2014)	Pure water and hybrid nanofluid (Al_2O_3+CuO)	10nm	Enhanced thermal performance by nanofluid than water
M.F. Zawrah et al., (2014)	Al_2O_3-Water	50nm	Enhanced thermal conductivity

2. MATERIALS AND EXPERIMENTAL WORK

2.1. Preparation of Aluminium oxide

Aluminium oxide is chemical compound of aluminium and oxygen. It is also called as alumina. In this study, alumina nanoparticles where mixed with water and ethylene glycol and used as heat transfer fluid, this enables increase in thermal conductivity (k) as well enhanced heat transfer performance. Alumina is most common nano particle used by many researchers, since it is readily available and reasonable priced, also because of its excellent combination of properties it has wide range in its applications. The thermal conductivity of nanoparticle is increased by increasing volume fraction of nanoparticles, with decreasing particle size, the shape of particles can also influence the thermal conductivity of nanofluids, temperature, Brownian motion of the particle, interfacial layer [3].

Researches carried out to study the thermophysical properties of nanofluids, shows that alumina nanofluids are very good electric insulators, good thermal conductivity, high corrosion conductivity, low density, excellent size and shape capability, available in various purity range.

For the preparation of nanofluid, base salt $NaNO_3$-KnO_3 (60:40) ratio 100ml is mixed with 10g of Al_2O_3 (10µm powder) to form the base salt nano fluid. Al_2O_3 nanoparticles used in this study is of 99% purity, which is added to 1 litre of water to form the nanofluid mixture which is used for circulation in the coolant circuit instead of plain water. Mixing of nanoparticles with water is done by direct synthesis method. This sample was used for experimental performance. The figure 1 shows the prepared alumina/water nanofluid. The table 2 gives the specification of alumina used in this project.

Fig-1: Prepared alumina/water nanofluid

Table 2: Properties of Alumina nanoparticles

Sr.No	Chemical name	Alumina
1	Particle size	10-30 nm
2	Particle shape	Spherical
3	Appearance	White powder
4	pH value	6.6
5	Density	3.97 gm/cm3
6	Specific surface area	15-20 m2/gm
7	Crystal form	Alpha
8	High purity	99%
9	Thermal	36 W/ m-K
10	Special heat of particle	1.923 kJ/kg·K

2.2 Ethylene Glycol And Water

Ethylene glycol and water is used as a base fluid for aluminium oxide particles. Ethylene glycol is commonly used as coolant and heat transfer agent. It is odourless, colourless and moderately toxic. Distilled or De-ionized water should be used for ethylene glycol solutions.

2.3 Heat Pipes

In this experimental study, the hybrid vortex sintered copper heat pipe cold plate is used. This hybrid liquid cold plate assemblies are designed specifically for unique application. These cold plates are designed to perform with diverse coolants, including water, water/glycol solutions, dielectric fluids, oils and synthetic hydrocarbons. The figure 2 shows the aluminium cold plate fitted with sintered copper heat pipe press fitted on one end.

Fig- 2: Hybrid vortex aluminium plate with sintered copper heat pipe

Heat pipe are available in standard dimensions from 3mm to 12mm and in lengths from 50mm to 250mm. Considering the heat pipe system is to extract 60% of heat load, thus the heat pipe to be selected is to have a minimum capacity of 30 watt. The heat pipe was made from sintered wick copper tube with an outer diameter of 32mm, length of 75mm. It is mainly divided into three sections namely evaporator, condenser and adiabatic sections having length of 30mm, 30mm and 15mm respectively.

The technical specifications of heat pipe as follows:

Table 3: Specifications of Heat Pipe

Components	Dimensions
Heat pipe	75mm
Evaporator	30mm
Adiabatic	15mm
Condenser	30mm
Outer Diameter	32mm
Tolerance Diameter	(+0.00,-0.05)
Tolerance Length	(+/- 0.5)
Cooling Fluid	Sintered copper powder

Fig- 3: Sintered copper heat pipe

2.4 Some of the properties discussed are:

2.4.1 Logarithmic mean temperature difference ΔT_{lm} :

The total heat transfer rate between the hot and cold fluids is calculated by using overall heat transfer co-efficient and surface area.

$$Q = UA\,\Delta T_{lm}$$

$$LMTD = \frac{\theta_2 - \theta_1}{Log_e \frac{\theta_2}{\theta_1}}$$

$$\theta_1 = T_{hi} - T_{ci}$$
$$\theta_2 = T_{ho} - T_{co}$$

In this study counter flow arrangement is used, since LMTD for a counter flow unit is always greater than that for a parallel flow unit. The counter flow unit needs smaller heating surface for the same rate of heat transfer.

2.4.2 Overall heat transfer co-efficient:

The overall heat transfer co-efficient depends upon the flow rate of fluids, properties of the fluids, thickness of material, geometrical configuration of the heat exchanger. It is directly proportional to heat transfer rate. Higher the value of overall heat transfer co-efficient, higher will be the heat transfer rate.

2.4.3 Capacity Ratio:

It is the ratio of minimum heat capacity rate to maximum heat capacity rate. When the capacity ratio increases, the effectiveness of heat exchanger decreases.

2.4.4 Effectiveness:

It is function of NTU and capacity ratio. It is ratio of actual heat transfer rate by heat exchanger to maximum possible heat transfer rate. Its value lies between 0 and 1, which depend on the geometry of the heat exchanger and flow arrangement. It enables in determining the heat transfer rate .

2.4.5 Resistivity:

It is ratio of temperature gradient and heat transfer rate. Lower the resistivity, better the heat transfer rate.

2.5. Experimental Set up

The experimental setup consist of hybrid vortex aluminium test block which was mounted by glass cover with the help of water tight adhesive to make it leak proof and to visualize the fluid flow. Flat plate heaters was attached at the bottom of the block to heat the fluid flow. Liquid contained by the fluid tank was driven by the pump at different flow rates. Stopwatch is used to measure flow rate. Flow regulating valve is attached before stopwatch to adjust the flow. Thermocouples were used to measure the temperature respectively at inlet and outlet of mini channel. Coolants used in the experiment are distilled water, nanofluid containing alumina nanoparticles at 0.05% vol. The Figure 4 shows the experimental setup.

Fig- 4: Experimental setup

The experiment was tested initially by pumping hot water from evaporator side. The hot water and cold water was measured at different flow rates. The water in the hot water was heated by heater having maximum wattage range of 100 watts. The water is heated in the range of 50 to 70°C. Simultaneously, cold water was pumped in the condenser side. The heat of hot water from the evaporator side transfers through the heat pipe. The sintered copper wick carries the heat from evaporator side to the condenser side. The cold water circulating absorbs the heat and cools the wick. Due to capillary action the cooled wick flows back to the evaporator side absorbs heat and the cycle is repeated. The temperature gradient reading for both hot water evaporator side and cold water condenser side were measured.

The same procedure was repeated for second trial and testing with Al_2O_3 nanofluid. The evaporator side was pump by hot water temperature ranging from 50 to 70°C. The condenser side was replaced by alumina nanofluid. In this test, the heat absorbed by sintered copper wick of heat pipe was transferred and cooled by Al_2O_3 nanofluid. The temperature gradient reading for both hot water evaporator side and nanofluid condenser side were measured. The temperarture of cold water and nanofluid were measured at room temperatures.

All the readings were measured under steady state. Samples of each fluid were collected to measure their properties such as heat transfer coefficient, thermal conductivity, thermal resistivity, LMTD, capacity ratio etc. Stopwatch is used to measure the flow rate. Flow regulating valve is attached before the stopwatch to adjust the flow. Thermocouples were used to measure temperatures at inlet and outlet of the mini channel. The heat input is kept constant and heat pipe is placed in horizontal position.

3. MATHEMATICAL FORMULAE

The thermal performance of heat pipe is measured in terms of thermal resistance and heat transfer co-efficient. The thermal resistance of heat pipe depends on heat input and temperature difference between evaporator and condenser. The thermal resistance is calculated by the formula:

$$R = \frac{T_e - T_c}{Q}; Q = VI$$

The heat transfer co-efficient of heat pipe depends on heat input, surface area of evaporator section and temperature difference between evaporator and condenser side. Overall heat transfer co-efficient is given by the formula:

$$h = \frac{Q}{A_S(T_e - T_c)}; A_s = \pi\, d_o\, Le$$

4. RESULTS AND DISCUSSION

4.1 Effect of Logarithmic Mean Temperature Difference

When the LMTD is calculated with hot water evaporator and cold water condenser side, it is observed that LMTD decreases with increase in flow rate, for both the trials.

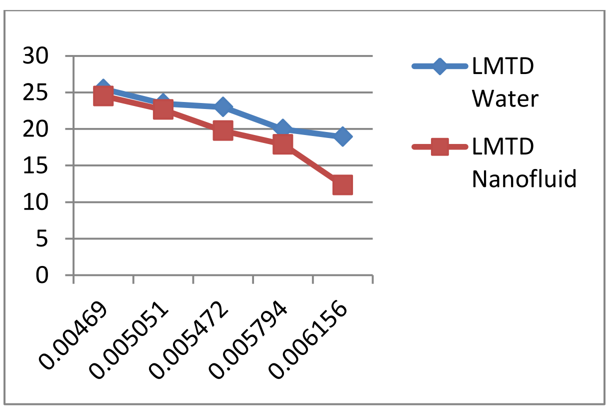

Chart 1: Comparison of LMTD versus mass flow rate (m^3/sec)

From the Chart 1, it is observed that the LMTD decreases with increasing flow rate of water and nanofluid. It is closely observed that the decrease in LMTD for Al_2O_3 nanofluid is much more comparatively to water. When the value of LMTD is larger, more is the heat transfer taken place.

4.2 Effect of Capacity Ratio

From the chart 2, it is observed that for varying flow rates, in both the tests, the capacity ratio went on decreasing with increasing flow rates. The capacity ratio of Al_2O_3 nanofluid is slightly less than the capacity ratio of plain water.

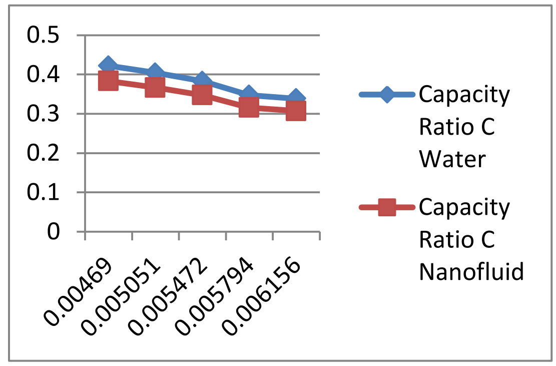

Chart 2: Comparative graph of Capacity Ratio versus mass flow rate (m^3/s)

4.3 Effect of Overall Heat transfer co-efficient

The effect of overall heat transfer co-efficient on varying flow rates is shown in the Chart 3. The overall heat transfer co-efficient increases with increase in flow rate and overall heat transfer co-efficient of Al_2O_3 nanofluid system is considerably higher than the plain water system indicating that the nanofluid system works better than the plain water system.

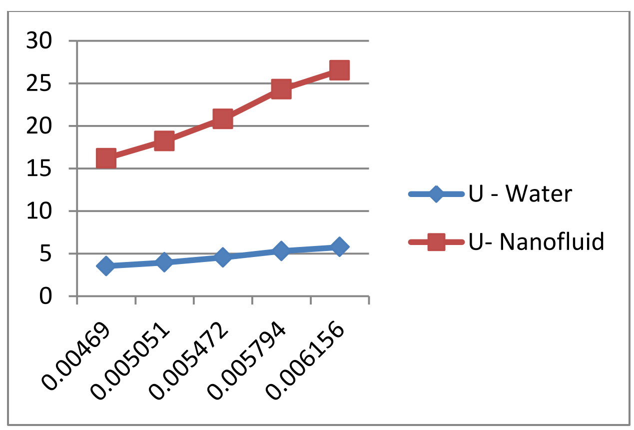

Chart-3: Comparison between Overall heat transfer co-efficient and mass flow rate.

4.4 Effect of Effectiveness

From the Chart-4, the effectiveness increases with increase in flow rate. The effectiveness of Al_2O_3 nanofluid is considerably higher than the plain water system indicating that the Al_2O_3 nano fluid system works better than the plain water system.

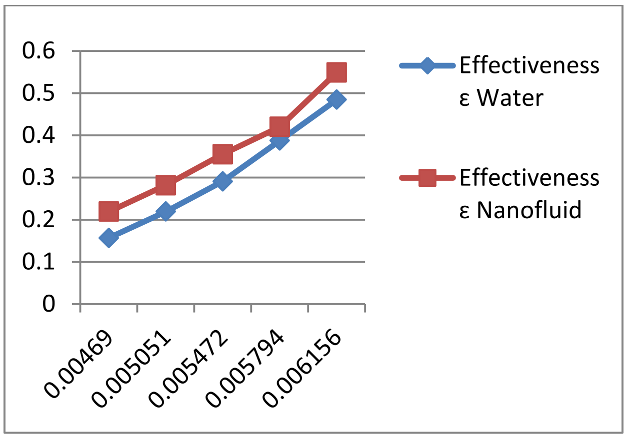

Chart-4: Comaparison of Effectiveness versus mass flow rate

4.5 Effect of Resistivity

The effect of resistivity from the Chart-5, indicates that the resistivity of heat pipe in case of plain water system is much more as compared to resistivity of heat pipe in case of nanofluids. Thus, the heat pipe works more effectively with the Al_2O_3 nanofluid system as compared to plain water system.

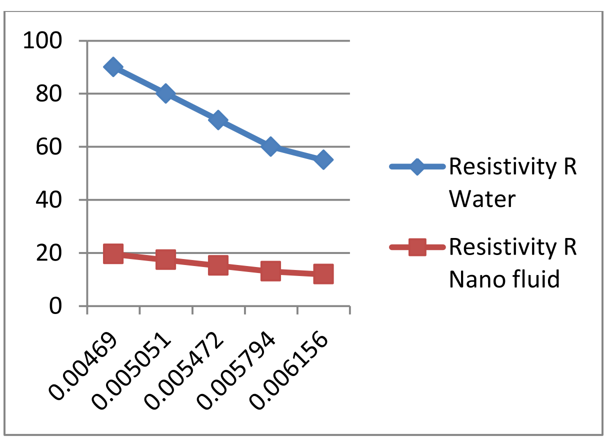

Chart-5: Comparison of Resistivity versus mass flow rate

5. CONCLUSION

The following are the main conclusions of this experimental investigation:

1) The experimental results shows that the overall heat transfer coefficient increases with increase in flow rate, and overall heat transfer coefficient of nanofluid system is considerably higher than the plain water system indicating that the nanofluid system works better than the plain water system.

2) The Effectiveness increases with increase in flow rate and Effectiveness of nanofluid system is considerably higher than the plain water system indicating that the nanofluid system works better than the plain water system.

3) Resistivity of heat pipe in case of the plain water system is much more as compared to resistivity of heat pipe in case of nanofluids; this indicates that the heat pipe works more effectively with the nanofluid system as compared to plain water system.

4) LMTD decreases with increase in flow rate for both the fluids; the percentage difference in decrease is very minor.

5) Similarly, capacity ratio decreases with increase in flow rate for both fluids with negligible difference between both the fluids.

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