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Analyzing the Effectiveness of Al_2O_3 Nanofluid as a Coolant in Sintered Copper Heat Pipes

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ABSTRACT

Experiment aims to compare the thermal properties of present thermal system using pure water & Al_2O_3 /water nanofluid as coolant. The thermal system consists of two mini channel heat sinks (Hybrid-vortex Aluminum Plate) and sintered copper powder heat pipe. The heat pipe is used as heat transfer media which is press fitted between two mini channel heat sinks. Hot water is circulated through one heat sink to heat the evaporator side of heat pipe. The heat is transferred through heat pipe. The condenser side of heat pipe is cooled by using coolant through another heat sink. The coolant is passes through heat sink at 5 different flow rates. The temperature at inlet and outlet of two heat sinks is measured with calibrated thermocouple & analyzed the results for 5 different flow rates. The compared thermal properties are overall heat transfer coefficient, heat transfer rate, effectiveness and resistivity. The experimental results show that the higher improvement of thermal properties using nanofluid as compared to pure water. The heat transfer rate by using Al_2O_3 /water nanofluid is enhanced up to 53.54% more as compared to pure water.

Keywords: *Heat pipe, Nano fluid, Heat transfer coefficient, Heat transfer rate, Effectiveness, Thermal resistivity.*

1. INTRODUCTION

The last few decades of the twentieth century have seen unprecedented growth in electronics, communication, and computing technologies, and it is likely to continue unabated into the present century. The exponential growth of these technologies and their devices through miniaturization and an enhanced rate of operation and storage of data have brought about serious problems in the thermal management of these devices. Another important area that has experienced a similar problem in thermal management is the area of optical devices. Lasers, high-power x-rays, and optical fibers are integral parts of today's computation, scientific measurement, material processing, medicine, material synthesis, and communication devices. The increasing power of these devices with decreasing size also calls for innovative cooling technology. However, the conventional fin-and-micro channel technology appears to be inadequate for the new generation of electronic and optical devices. Power densities of 2000 W/cm^2 can be managed by micro channel heat exchangers that use subcooled liquid nitrogen.

An increasing number of studies on micro channel boiling indicate the need for an alternative way to cool micro-size devices. The advent of nanotechnology and Micro-Electro-Mechanical Systems (MEMS) has only intensified this need, asking for a revolution in cooling technology to keep pace with the new revolution in device technology.

However, it is important to note that miniaturized devices are not alone in looking for innovative cooling technology. Large devices (such as transportation trucks) and new energy technology (such as fuel cells) also require more

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efficient cooling systems with greater cooling capacities and decreased sizes.

Thus, big or small, new and enhanced cooling technology is the need of the hour. This need must be met in two ways: introducing new designs for cooling devices, such as micro channel and miniature cryo devices, and enhancing the heat transfer capability of the fluid itself.

Electronic equipment's are being used in every aspect of modern life; from toys and home appliances to high power computers; from space systems to process industries. The reliability of the electronic components of a system is a major factor in the overall reliability of the system. Heat generation is an inescapable factor in all these systems. Continued miniaturization of the electronic circuits and the resulting high packing density has resulted in a dramatic increase in heat generation. A high rate of heat generation leads to corresponding high operating temperature of the electronic components which compromises its safety and reliability resulting in the higher failure rate of the systems. Hence the thermal control is an important factor in the operation of electronic equipment.

2. LITERATURE REVIEW

A significant number of studies have been available on minichannels, nanofluids and heat pipes, which has been review in papers as follow:

1. Kamal Kumar Bansal Performed evaluation of heat sinks for electronic cooling using (H_2O & Al_2O_3-H_2O) as a coolant. Experiments were done on the mini channel with dimensions 2.7 mm depth and 2.95 mm width which was made on the aluminum heat sink.

He concludes that

- Density and viscosity of nanofluids have decreased with increase in temperatures whereas both have increased on addition of nanoparticles. The changes in viscosity were more significant with temperature than change in density.
- Thermal conductivity of nanofluid has increased with increase in temperature. The conductivity has shown significant increase on addition of nanoparticles at higher temperatures.
- Temperature difference between inlet and outlet of minichannel has decreased with increase in Reynolds number due to decrease in available time for heat transfer.

2. G. Kumaresan, S. Venkatachalapathy, gave review on heat transfer enhancement studies of heat Pipes using nanofluids. The review reports the use of conventional fluids and different nanofluids with varying mass/volume fractions in heat pipes.

- Nanoparticles like Ag, Au, Cu, CuO and Al2O3 were dispersed in various base fluids. Replacing the conventional fluid by nanofluid reduces the dry out problems and enhances the heat transfer capacity.
- Improvement in thermal efficiency and reduction in thermal resistance is witnessed with increasing mass/volume fraction of nanoparticles in base fluids.
- Orientation of the heat pipe also affects its thermal performance. The optimum performance is obtained at a tilt angle of around 60° for wick heat pipes and vertical position for thermosyphon heat pipes.
- Size of nanoparticles and its concentration has a strong influence on the temperature distribution. Effect of heat pipe geometry and its impact on heat transfer characteristics could be explored in future.

3. Rana Ashvini R, et al., has done Experimental Investigation of Heat Transfer Enhancement of Heat Pipe using Silver/Water Nanofluid. From experimental results, it is concluded that

- The heat transfer coefficient increases with the increase in heat input. Thermal resistance decreases as heat input increases.
- As nanoparticles dispersed in working fluid, the increase in wall temperature of heat pipe is lower compared to water.

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Hence, the thermal performance of heat pipe is improved.

- Thermal resistance of heat pipe decreases by 6.85-17.7% and heat transfer coefficient increases by 6.88-15.63% with silver/water nanofluid compare to DI water.
- Thermo-physical properties of nanofluid are higher than that of the base fluid water. The enhancement in thermal conductivity of silver water nanofluid is 8.78%.

4. Patrik Nemec et al., presented details and results of an investigation on thermal performance measurement of heat pipe.

- From experimental measuring thermal performance of heat pipes are create graphic dependences average values of thermal performance from working position of heat pipe. Ideal working position of heat pipe is vertical position.
- Heat pipe operate on maximum performance and maximum mass flow transfer in this position.
- This experiment has testified that the wick heat pipe is able to operate at any other position as vertical and even at the horizontal position. From results measured performances of heat pipes at various working position discover that the wick heat pipe is able operate at horizontal position and total heat performance transfer is not very different as at vertical position, which capillary structure cause.

3. EXPERIMENTAL SETUP

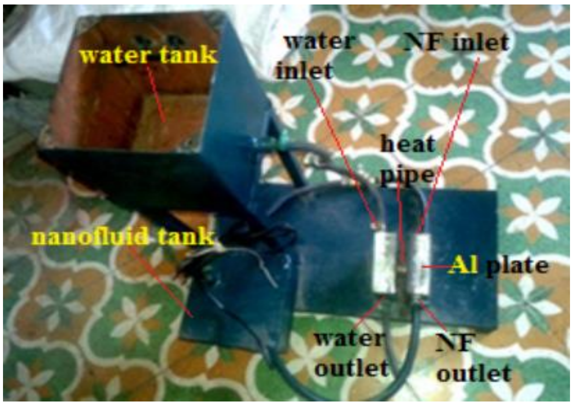

Fig. 1: Experimental Setup

3.1 Components of Experimental Setup

- Sintered Copper Powder Heat Pipe
- Aluminium Heat Sink (Hybrid Vortex Al Plate)

Fig 2: Hybrid Vortex Al Plate with Heat pipe

Dimension of Aluminium plate

Length=100mm

Width=100mm

Thickness=30mm

Diameter of Hole to fit heat pipe=32.2mm

Depth of Hole=25mm

- Heater
- Water Tank (Top Tank)
- Coolant Tank (Bottom Tank)
- Pump
- Stopwatch
- Beaker
- Thermocouple
- Rubber Hosing
- Flow Control Valve

3.1.1 Heat Pipe Dimensions

- Length = 75 mm long
- Evaporator length = 25 mm
- Condenser length = 25 mm
- Adiabatic length = 25 mm
- Diameter = 32 mm

3.2 Purpose of Study

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The following specific objectives are undertaken:

1. To experimentally investigate the thermos-physical parameters of heat pipe through minichannel hybrid vortex Al plate coolant used water and Al_2O_3/water based nanofluid.
2. Design and development of Hybrid –Vortex sintered copper heat pipe cold plate (Heat sink).
3. Preparation of Al_2O_3 nanofluid by dispersing Al_2O_3 nanoparticles in water and EG to investigate experimentally the thermos-physical properties of nanofluid.
4. Experimental analysis of the heat pipe with different cooling medium
   a) Water without addition of nanofluids
   b) Water – with aqueous solution of nanoparticles (Aluminum powder 10μm).
   c) Testing will be done to find the parameters of the system for each working fluid are Heat Transfer Coefficient, Heat Transfer Rate, Effectiveness and Thermal resistivity.
   d) To carry out comparative study of theoretical and experimental analysis results to decide the heat pipe parameter optimization in different flow rate of coolant.

3.3 Experimental Procedure

1. All the pipeline connections are checked for leakage and pump is switched on to check the flow of coolant in the circuit.
2. After this mass flow rate at 5 different speed is measured with beaker & stopwatch arrangement.
3. After setting the required flow rate, then heater is switched on, steady state was reached in 10-15 minutes.
4. From evaporator side, hot water at 60^0C is flows through one Aluminum heat sink simultaneously plain water at 28^0C from coolant tank passed from condenser side through another Aluminum heat sink.
5. Temperature at inlet and outlet was measured with the help of thermocouples & calculated the thermal properties such as overall heat transfer coefficient, heat transfer rate, thermal resistivity & effectiveness by using formulae.
6. **6.** Repeating the procedure for Al_2O_3/water nanofluid as coolant for condenser side through heat sink.

3.4 Detail properties of nano fluid

Composition of the nano fluid is as follows:

Material	Nanoparticle concentration wt.%	Specific heat (solid phase; kJ/kg·K)	Enhancement (Solid phase; %)	Specific heat (liquid phase; kJ/kg·K)
Base salt + Al_2O_3	5	1.923	19.9	1.745

Specific heat of water + (BASE SALT +Al2O3) at (25 to 30 ^{0} C) = 4.6035 kJ/kg-k

3.5 Preparation method of nanofluid

In this work nanofluid was prepared by two step method where the given nanoparticle is mixed to the base fluid to obtain suspension. Nanoparticles Al_2O_3 of particles diameter size 10 nm were purchased. Base Salt $NaNO_3$-KnO_3 – (60:40) ratio 100 ml is mixed with 50g of Al_2O_3 (10nm powder) to form the base salt nano fluid which is added to 1 litre of water with little surfactant EG (to prevent aggregation) was taken and hydrolysed with water to form the nanofluid mixture for 20 minutes at the rate of 1000 rpm by magnetic stirrer, maintaining at temperature of 60^0 C to maintain PH value of solution above 6 to critical value of 10.5. Timely measure a solution with PH-meter.

3.6 Calculations Terminology

Thi = Temperature of hot water at inlet

Tho = Temperature of hot water at outlet

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Tci = Temperature of cold water at inlet

Tco = Temperature of cold water at out let

LMTD

$(\theta m) = (\theta 1 - \theta 2) / \ln(\theta 1 / \theta 2)$

Where $\theta 1$ = Thi –Tco

$\theta 2$ = Tho –Tci

The overall heat transfer coefficient

Q = U x A x θm = m Cp DT

Here

A = wetted area of heat pipe

Considering evaporator length = condenser length = 30 mm

Diameter of heat pipe = 32 mm

Area = πDL = 3.142 x 0.032 x 0.03 =0.00316 m^2

Capacity ratio (C):

C = (m Cp) small / (m Cp) large

Effectiveness (ε)

ε = (Thi – The) / (Thi - Tci)

Resistivity of the heat pipe system (R)

q= ΔT / R

4. RESULTS & DISCUSSIONS

4.1 LMTD

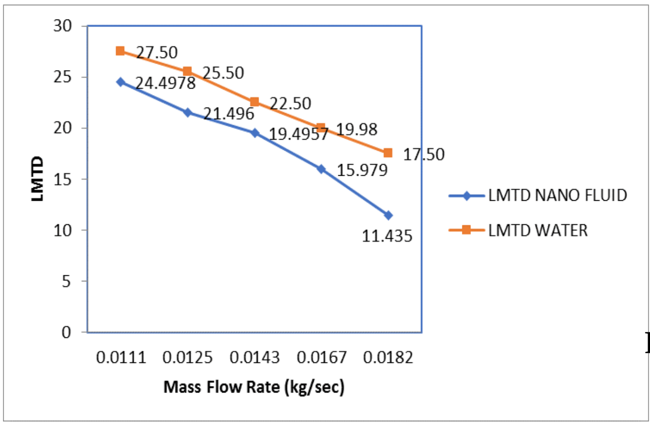

Fig. 3: Comparison of LMTD

Above figure 3, shows LMTD drops with increase in mass flow rate for both fluids due to turbulent flow. Under turbulent flow the value of temperature difference increases with the increase in mass flow rate. And hence LMTD goes on decreasing. LMTD for nano fluids slightly less than that of plain water.

4.2 Overall Heat Transfer Coefficient

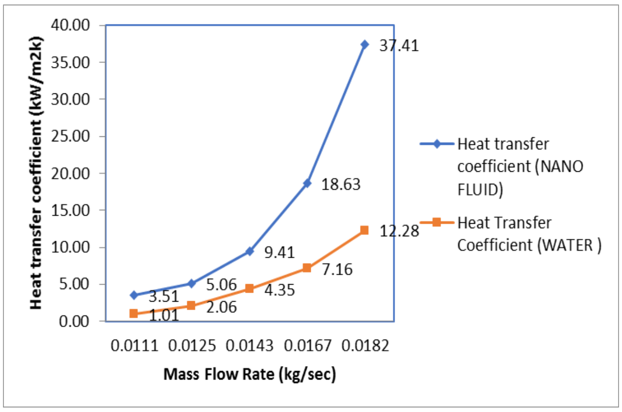

Fig 4: Comparison of Overall Heat Transfer Coefficient

Above figure 4, shows that the Overall heat transfer coefficient increases with increase in flow rate, and overall heat transfer coefficient of nano fluid system is considerably higher than the plain water system indicating that the nano fluid system works better than the plain water system.

4.3 Heat Transfer Rate

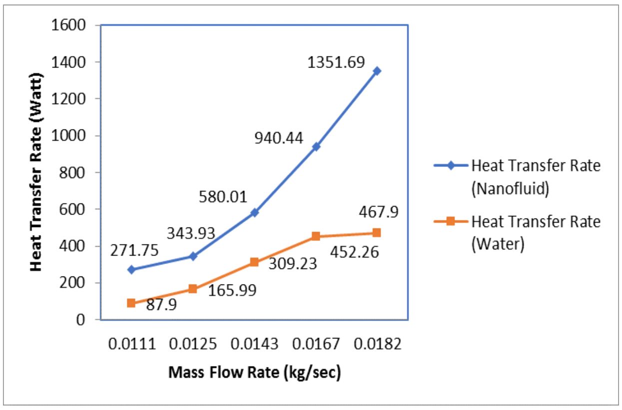

Fig 5: Comparison of heat transfer rate

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Above figure 5, shows that Thermal Conductivity increases with increase in flow rate, and Thermal Conductivity of nanofluid system is considerably higher than the plain water system indicating that nano fluid system works better than the plain water system.

4.4 Effectiveness

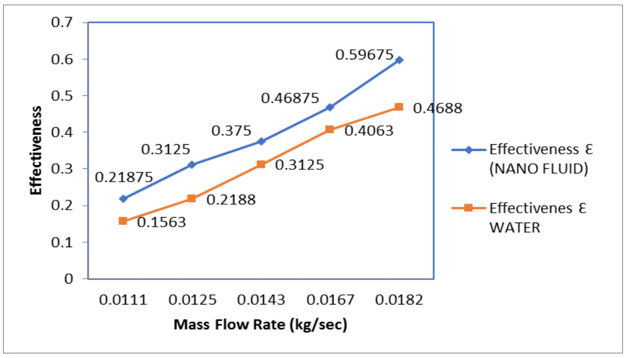

Fig 6: Comparison of Effectiveness

Above figure 6, shows that Effectiveness increases with increase in flow rate, and Effectiveness of nano fluid system is considerably higher than the plain water system indicating that the nano fluid system works better than the plain water system.

4.5 Resistivity

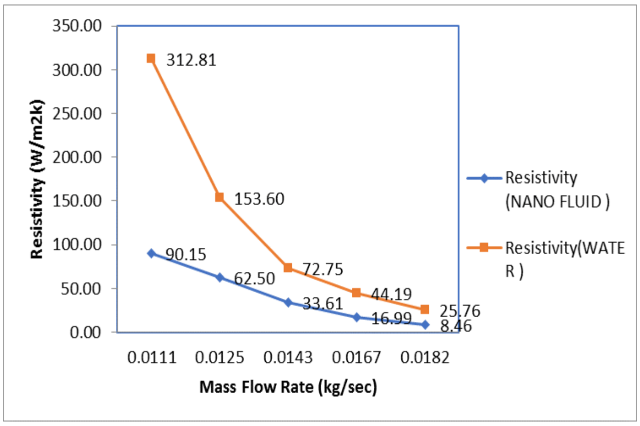

Fig 7: Comparison of Resistivity

Above figure 7, shows that 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 nano fluid system as compared to plain water system.

5. CONCLUSION

- Experiment analysis proved that thermo-physical properties of nanofluid has higher value than that of the plain water as coolant in thermal system are as follows-
  - Thermal conductivity of non-metal nanoparticles increased with increase in temperature of nanofluid. Because of increase in lattice vibration, thermal conductivity of non-metals goes on increasing. The thermal conductivity of nanofluid has shown significant increase on addition of nanoparticles.
  - Overall heat transfer coefficient of the present thermal system with nanofluid as coolant has 60.99% higher than the plain water as coolant. Because overall heat transfer coefficient is influenced by the thickness & thermal conductivity through which heat is transferred. The enhancement occurs due to increase in thermal conductivity due to suspension of nanoparticles and large energy exchange due to nonlinear movement of nanoparticles.
  - Heat transfer rate of the present thermal system with nanofluid as coolant has 53.54% higher than the plain water. Heat transfer rate increases with increase in mass flow rate. Heat transfer rate is directly proportional to the overall heat transfer coefficient. As larger the overall heat transfer coefficient, the easier heat is transferred & hence as overall heat transfer coefficient increases, heat transfer rate also gets increases.
  - Effectiveness of the present thermal system with nanofluid as coolant has 21.92% higher than the thermal system with water. The effect of dispersion of the nanoparticles in

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base fluid gives increases in the effective thermal conductivity and specific heat such that the effectiveness further increased with increasing the mass flow rate.

- The thermal resistance of the present thermal system with nanofluid as coolant has 62.6 % higher than the thermal system with plain water as coolant. Because the thermal resistance is reciprocal of thermal conductivity. By experimental analysis it is proved that thermal conductivity is increased with increase in mass flow rate, hence thermal resistance goes on decreasing with increase in mass flow rate. This indicates that the thermal system works more effectively with the nanofluid as compared to plain water as coolant.
- The present study shows that thermal system with heat pipe has improved thermal performance by using nanofluid instead of plain water as a cooling medium.

6. REFERENCES

1. Kamal Kumar Bansal, "Performance evaluations of heat sink for electronic cooling using (H_2O & Al_2O_3-H_2O) as a coolant" M.E. Thesis, Dept. of Mechanical Engineering, Thapar University, Patiala – 147004, July 2015.
2. G. Kumaresan, S. Venkatachalapathy, "A review on heat transfer enhancement studies of heat Pipes using nanofluids", Frontiers in Heat Pipes (FHP), Vol-3, 043001, 2012.
3. Rana Ashvini Ra, V. D. Dhimanb, Jignesh J.Patel, "Experimental investigation of Heat Transfer Enhancement of Heat Pipe using Silver/Water Nanofluid", University Journal of Research Vol. 01, Issue 01,2015.
4. Nur Atikah Bt Ali, "Preparation and characterization of physicochemical Properties of Aluminum Oxide (Al_2O_3) – water (H_2O) nanofluids Using two step methods", M.E. Thesis, Faculty of Chemical & Natural Resources Engineering University, Malaysia Pahang, December 2010.
5. Patrik Nemec, Alexander Caja, Milan Malcho, "Thermal Performance Measurement of Heat Pipe", Global Journal of Technology & Optimization, Transaction on Thermodynamic and Heat Transfer, ISSN: 2229-8711 Online Publication, Volume-2, PP 104-110, June 2011.
6. B. Naga Murali, Kudumala Govardhan Reddy,P. Kranthi Kumar, "Design, Analysis And Fabrication of Heat Pipe", International Journal of Research In Aeronautical And Mechanical Engineering,Vol-3 Issue 9, PP 1-9, September 2015.
7. Rupesh D. Khorgade1, R. S. Shelke, "Heat Transfer Enhancement Techniques of Minichannel Heat Sink Using Nanofluids: A Review", International Journal of Advance Research In Science And Engineering, Vol. No.3, Issue No.12, , PP 179-187, December 2014.
8. Zenghu Han, "Nanofluids With Enhanced Thermal Transport Properties", M.E. Thesis, Department of Mechanical Engineering University of Maryland at College Park College Park, Maryland
9. Fabian Korn, "Heat Pipes and Its Applications", M.E. Thesis, Dept. of Energy Sciences, Faculty of Engineering, Lund University, Sweden, May 07, 2008.
10. Mr. A. Sivakumar, Dr. N. Alagumurthi and Dr. T. Senthilvelan, "Heat Transfer Enhancement of Serpentine Shaped Micro Channel Heat Sink with Al_2O_3/Water Nanofluid", International Journal of Technical Research and Applications e-ISSN: 2320-8163, www.ijtra.com Volume 2, Issue 4, PP. 112-116, July-Aug 2014.