Effect of CuO/Water Nanofluid in the Enhancement of Convective Heat Transfer for Electronic Cooling

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ABSTRACT

Electronic components generate heat as a by product in their operation. Effective handling and dissipation of the heat generated is essential for the development of reliable electronic components. In this work, copper oxide nanoparticles of average size 16nm are synthesized by sol gel method. Then the water based nanofluids of low volume concentrations of 0.1% and 0.2% are prepared by dispersing the required quantity of copper oxide nanoparticles in deionised water. A copper heat sink of overall dimensions 100x100 mm with macro rectangular channels is used for the present study. The prepared nanofluids are tested in the copper heat sink and their convective heat transfer performance and pressure drop characteristic are compared with the deionised water. It is found from the experimental results that the average increase in convective heat transfer coefficient of heat sink when CuO/water of 0.2% volume concentration nanofluid is used as the working fluid is 17.8% compared to deionised water while there is no significant rise in pressure drop due to the use of nanofluids.

Keywords: Rectangular channel heat sink, CuO nanoparticle synthesis, CuO/water nanofluid, Interface temperature, Convective heat transfer coefficient.

1 INTRODUCTION

Cooling of electronic components have attracted widely by the researchers due to increasing heat flux from the electronic components as the demand for processing speeds and high power electronic systems increases tremendously and the increasing demand for reduction in size of the components [1]. It is expected that the heat flux from the electronic chips may increase to 100 W/cm^2 in near future. If the heat from the components is not effectively removed, it will affect the performance of the system and even may damage the components. Efficient removal of heat will also retain the expected life span of the components with desired functioning characteristics. Rate of components failure increases exponentially as the component temperature increases.

Removal of heat from the electronic components using finned surfaces with air as the coolant is reached its capacity limits as the air is possessing very low thermal conductivity, specific heat capacity and density. Liquid cooling of electronic products overcome the difficulties posed by air cooling since liquids have very high thermal conductivity and specific heat capacity compared to air.

Thermal conductivity of the conventional heat transfer fluids are very low compared to solids. Dispersing nano sized solid particles into the base fluids such as water or ethylene glycol improves the thermal conductivity of base fluids which in turn increases the convective heat transfer performance of fluids. Nanofluid a term invented by S.U.S. Choi of Argonne National Laboratory of USA [2] in the year 1995. Nanofluids offer so many advantages like (i) improved thermal conductivity (ii) Enhanced stability of the nanofluids (iii) small rise in viscosity due to the inclusion of solid particles (iv) reduced erosion. The increase in thermal conductivity is attributed to (i) Brownian motion of the nano scale particles (ii) Liquid layering (iii) particle clustering [3].

Lee et al. [4] experimentally measured thermal conductivities of water and ethylene glycol based oxide nanofluids using transient hot wire method. They found from their experimental results that for the same nanoparticles enhancement in thermal conductivity ratio of ethylene glycol based nanofluids is higher than water based nanofluids. Chandrasekar et. al [5] investigated the thermal conductivity and viscosity of Al_2O_3/water nanofluids of different volume concentrations theoretically and experimentally. They concluded that the thermal conductivity increase linearly with particle volume concentration. Also they developed theoretical model for predicting thermal conductivity and viscosity without resorting available standard models. Numerous experimental studies on the convective heat transfer performance of the nanofluid have also been carried out. [6-10].

Micro channel heat transfer is another technique to improve the heat transfer capability of the heat sinks for electronic components. Numbers of experimental and numerical studies are done by the researchers with various geometrical configurations and fluids. M. Reyes et.al [11] conducted experiments to investigate heat transfer and pressure drop characteristics of water in a micro channel heat sink. They used a heat sink made of copper machined with square channels of size 500 µm with the overall dimensions of 15 mm x 15 mm. They studied the effect of tip clearance on the heat transfer and pressure drop compared to the heat sink without any tip clearance. They observed from their experiments that the tip clearance works well in terms of heat transfer and pressure drop. Weilin Qu et. al [12] studied heat transfer and pressure drop characteristics of micro channel heat sink of channel dimensions 231 µm wide and 713 µm deep with two heat fluxes of 100 W/cm^2 and 200 W/cm^2.

They conducted experimental and numerical investigations. They analysed the performance of micro channels in the Reynolds number range of 139 to 1672 and observed that fluid outlet temperature and heat sink temperature reduces at higher Reynolds number flows but at a higher pressure drop.
Nguyan et al.[13] conducted experiments using Al_2O_3/water as the coolant in a commercially available electronic heat sink used for cooling of microprocessors. In their experiments, they studied the effect of particle volume concentration and particle size on the convective heat transfer performance of the fluid. They obtained 40% increase in convective heat transfer coefficient for 6% volume concentration of nanofluid compared to water. Gherasim et al. [14] investigated the heat transfer performance of Al_2O_3/water nanofluid through a radial flow cooling device and found that the Nusselt number increases with volume concentration and Reynolds number, but it decreases with increase in spacing between the heated plate and the disk. Roberts et al. [15] conducted experiments using Al_2O_3/water nanofluid in a commercially available water block. An enhancement of 20% in thermal conductance has been reported for the nanofluid prepared using 20-30 nm alumina nano particles in the commercial water block.
In the present work we have synthesised CuO nano powder and water based nanofluid and studied the heat transfer and pressure drop characteristics of this fluid in a macro rectangular channelled copper heat sink.

2 EXPERIMENTAL SETUP

The experimental set up consists of a liquid cooled heat sink and a heated block made of aluminium. The schematic of the experimental set up is shown in Fig.1.Cartridge heater is used for heating the aluminium block which simulates the heat generated by any electronic component. The heat sink consists of rectangular channels of width 5.3 mm and length 68.7mm as shown in Fig.2. There are ten rectangular channels and the inlet flow starts from the centre of the heat sink and moves outwards from the centre towards left and right in order to make large temperature difference at the centre. Thermal Interface Material is applied at the interface to fill the microscopic asperities. Mechanical pressure is applied from the top of the water block to minimize the thermal resistance between the heated block and the heat sink. A thick layer of Poly Urethane Foam and Styrofoam insulations are applied all around the surfaces of the heated block and heat sink assembly to minimize the heat losses to the surroundings. Type K thermocouples of four numbers are inserted properly through the heated block to measure the interface temperature. The circulation of flow in the heat sink is made using a peristaltic pump. The inlet and outlet fluid temperatures are measured using two k type thermocouples with an accuracy of ±0.1^{o} C. The volume flow rate of the fluid is measured using a measuring jar and a stop watch. The inlet fluid temperature is maintained constant using a constant temperature bath. A 4 litre plastic container is used as a reservoir. The uncertainties associated with the Nusselt number, Reynolds number and pressure drop are respectively ± 3.8%, 1.8% and ± 1.7%.

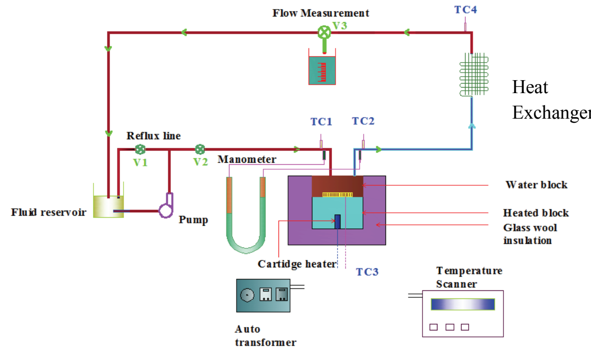

Fig. 1 Schematic of the experimental setup

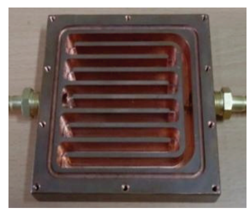
Fig.2 Photograph of the copper heat sink

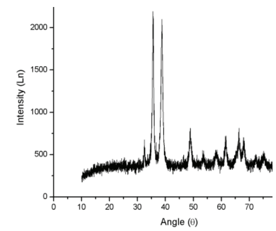

Fig.3 XRD pattern of synthesized CuO nanoparticles

3 EXPERIMENTS

3.1. Synthesis of Nanoparticle and Nanofluid

Nanocrystalline copper oxide (CuO) powder was synthesized in Sol–Gel method. NaOH solution of prescribed quantity is added to the $CuCl_2$ solution in dropwise fashion. The following reaction takes place.

$$CuCl_2 + 2NaOH \longrightarrow CuO + 2NaCl + H_2O$$

The solution is agitated using a magnetic stirrer and the gel formed was allowed to settle for a period of 2 hours. After the settlement the water from the top of the gel is removed and the precipitate was filtered. It was then dried and made in to powder form using a mortar and pestle. The XRD (X-ray Diffraction) spectra of the synthesised nano powder is shown in Fig. 3. The powder XRD was carried out with a Rigaku X ray diffractometer by Cu ka1 radiation in the range of 20–80°. The average particle size is determined to be 16 nm using the Scherrer formula. Nanofluids of 0.1% and 0.2% volume fractions are then prepared by dispersing a specified amount of nanoparticles in to the deionised water using an ultrasonicator which generates ultrasonic pulses at 25 KHz. No pH changers or surfactants are added to the nanofluid as this may have some influence on the thermal properties. To ensure the stability of the prepared nanofluid the pH of the prepared nanofluids is measured using a digital pH meter and it is around as 4.8. Since this value of pH is far from the isoelectric point of the CuO nanoparticles, the prepared nanofluids were stable.

3.2 Thermo Physical Properties Measurement

Thermal conductivity and viscosity of the prepared nanofluids are measured using KD2 Pro thermal property analyser and Brook filed viscometer respectively. The measured values of thermal conductivity and viscosity are used for heat transfer calculations.

4 DATA REDUCTION

Heat flux,

$$q = \frac{Q}{A} \qquad (1)$$

A = Exposed heat transfer area of the heat sink.

The convective heat transfer coefficient of the heat,

$$h_w = \frac{q}{(T_i - T_{fm})} \qquad (2)$$

Where T_i is the interface temperature and T_{fm} is the bulk mean temperature of the fluid.

Reynolds number is calculated using the following relation.

$$Re = \frac{4m}{\pi \mu D_i} \qquad (3)$$

5 RESULTS AND DISCUSSIONS

5.1 Interface Temperature

Fig. 4 shows the interface temperature measured between the heated aluminium block and the copper heat sink made of macro rectangular channels. The coolant enters at the centre and divided in to two flow paths from the centre to outer boundary of the heat sink to have a higher difference in temperature between the coolant inlet and the centre of the electronic components case for better heat transfer. As the volume flow rate of the coolant increases from 0.74 LPM to 2.22 LPM for the deionised water and the CuO/water nanofluids of two volume concentrations, there is a clear reduction in interface temperature. For the nanofluid of two volume concentrations the interface temperatures at all volume flow rates are less than the interface temperature shown by the water. Also the interface temperature decreases with increase in volume concentration of the nanofluid.

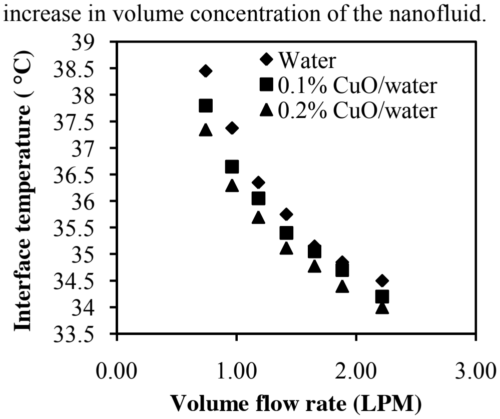

Fig. 4 Effect of nanofluid on interface temperature

5.2 Convective heat transfer coefficient

Fig. 5 explains the convective heat transfer of water and CuO/water nanofluids for different volume flow rates. For the heat sink to be more compact and efficient, the convective heat transfer coefficients of the heat sinks should be high. The value of convective heat transfer coefficients is depending on the thermal conductivity of the heat transfer fluid, flow geometry and the flow rate. From the figure it is understood that the convective heat transfer coefficient of the copper heat sink which contains macro rectangular channels increases with respect to the increase in volume flow rate of the water as well as CuO/water nanofluids. Also the convective heat transfer coefficient is more for all volume flow rates of CuO/water nanofluids compared to water. The average increase in convective heat transfer coefficient of the 0.2% CuO/water nanofluid compared to water is 17.8%. It can be observed from the figure that the values of convective heat transfer coefficients increases steeply for the volume flow rates upto 1.42 LPM and then the slope of the rise is flattened. The increase in convective heat transfer coefficient is attributed to the improved thermal conductivity of the nanofluid, thermal dispersion etc.

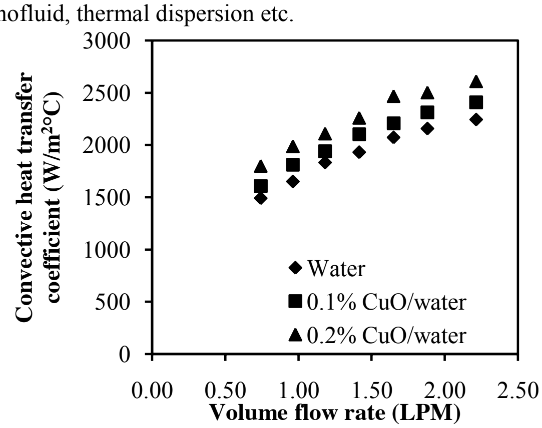

Fig.5 Effect of nanofluid on convective heat transfer coefficient

5.3 Pressure Drop Characteristics

Pressure drop in any heat exchanger system is vital as it decides the pumping power of the systems. Pressure drop characteristics of the water and nanofluids are shown in Fig.6 for the range of volume flow rates for which heat transfer studies were carried out. Pressure drops in the heat sink between the inlet and outlet at different flow rates were measured using a U – tube manometer which uses CCl4 as the manometric fluid. Pressure drop in the heat sink increases with increase in volume flow rate of the water and nanofluids and the rise in pressure drop of nanofluid compared to the water is very low. Hence there will be no significant rise in pumping power when the nanofluid is used as the heat transfer fluid compared to water. The average increase in pressure drop compared to water when 0.2% volume concentration CuO/water nanofluid is used as the working fluid is 7.85%.

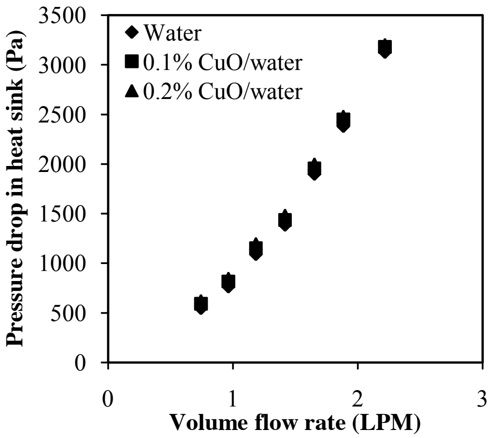

Fig. 6 Pressure drop in heat sink

6 CONCLUSIONS

CuO nanoparticles of average particles size 16 nm were synthesized in sol-gel method. CuO/water nanofluids of 0.1% and 0.2% volume concentrations were prepared by dispersing specified quantity of the synthesized nanoparticles in deionised water using an ultrasonic bath. Thermal conductivity and viscosity of the prepared nanofluids were measured experimentally. The heat transfer and pressure drop characteristics using water and prepared nanofluids have been studied in a macro rectangular channel copper heat sink to assess the performance of the nanofluids for electronic cooling. Nanofluids show a positive result in reducing the interface temperature compared to water. Also the convective heat transfer coefficient of heat sink is raised by 17.8% compared to de ionised water when CuO/water nanofluid of 0.2% volume concentration is used as the working fluid. There is no significant raise in pressure drop when nanofluid is used as the coolant in the heat sink compared to water which shows favourable sign to use nanofluid as the coolant for removing the heat loads in industrial applications such as electronic cooling systems.

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