International Journal of Mechanics and Thermodynamics.
ISSN 2278-361X Volume 5, Number 1 (2014), pp. 1-12

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Effect of CuO/ Water Nanofluid Heat Transfer IN Serpentine Shaped Microchannel Heat Sink

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Abstract

This research work speaks the heat transfer improvement in micro channels with nanosized particles of CuO and its flow channel. The nano materials and its suspension in fluids as particles have been the subject of intensive study worldwide recently since pioneering researchers recently discovered the anomalous thermal behavior of these fluids. The heat transfer from smaller area is achieved through microchannels. The heat transfer principle states that maximum heat transfer is achieved in microchannels with minimum pressure drop across it. In this research work the experimental and numerical investigation for the improved heat transfer characteristics of serpentine shaped microchannel heat sink using CuO/water nanofluid is done. The fluid flow characteristics is also analyzed for the serpentine shaped micrchannel. The experimental results of the heat transfer using CuO nanofluid is compared with the numerical values. The results in this work suggest that the best heat transfer enhancement can be obtained compared with base fluid by using a system with an CuO –water nanofluid-cooled micro channel with serpentine shaped fluid flow.

Keywords: Serpentine shaped,Microchannel Heat sink, Heat Transfer enhancement , Friction factor, Nanofluid CuO/water.

1. Introduction

With the advances in computing technology over the past few decades, electronics have become faster, smaller and more powerful. This results in an ever-increasing heat generation rate from electronic devices. In most cases, the chips are cooled using forced air flow. However, when dealing with a component that contains billions of transistors working at high frequency, the temperature can reach a critical level where standard cooling methods are not sufficient. In addition to high-performance electronic chips, high heat flux removal is also required in devices such as laser diode arrays and high-energy mirrors.

Advanced very large-scale integration (VLSI) technology has resulted in significant improvements in the performance of electronic systems in the past decades.With the trend toward higher circuit density and faster operation speed, however, there is a steady increase in the dissipative heat flux at the component, module, and system levels. It has been shown that most operation parameters of an electronic component are strongly affected by its temperature as well as its immediate thermal environment. This leads to an increasing demand for highly efficient electronic cooling technologies. To meet this demand, various electronic cooling schemes have been developed. Comprehensive reviews of the different heat transfer techniques employed in electronic cooling were provided by Mudawar [1] and Yeh [2].

The application of of micro channels in heat transfer was first proposed by Tuckerman and Pease [3] in the electronic chip which could be effectively cooled by means of water flow in microchannels fabricated on the circuit board on which the chips are mounted. The need for thermal management in high end power electronic workstations cooling, application servers and data centers [4] is an exceedingly demanding area that requires continuous research efforts to develop efficient and cost competitive cooling solutions. Some of the commonly used heat transfer fluids are the Air, ethylene glycol and engine oil for the past some decades[5].

The nanofluids were first introduced by Choi[6] in the Argonne National Laboratory, USA, who found that nano particles increases the thermal conductivity of the working fluid, thus improving the heat transfer performance. The researchers S. Lee, J. Koo[7,8] proved that nano particles has enhanced thermal conductivity than the base fluids which shows the nano sized particles has good potential in the thermal area.

Nanofluids are defined as suspension of nanoparticles in a basefluid. Some typical nanofluids are ethylene glycol based copper nanofluids and water based copper oxide nanofluids, Nanofluids are dilute suspensions of functionalized nanoparticles composite materials developed about a decade ago with the specific aim of increasing the thermal conductivity of heat transfer fluids, which have now evolved into a promising nanotechnological area. Such thermal nanofluids for heat transfer applications represent a class of its own difference from conventional colloids for other applications. Nanoparticles that are suspended in the base fluid will transfer heat with their Brownian motion and interactions. Considering these advantages, nanofluids attract more and more interests theoretically and experimentally.Compared to conventional solid–liquid suspensions for heat transfer intensifications, nanofluids possess the following advantages [9].

- Increased surface area therefore more heat transfer surface between particles and fluids
- High dispersion stability with predominant Brownian motion of particles.
- The pumping power is reduced as compared to pure liquid due to heat transfer intensification
- There is no particle clogging compared to conventional slurries which results in system miniaturization
- Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications.

Microscale heat exchangers are being used to help along the development of fuel cells. The compact microchannel fuel vaporizer (CMFV), which is a microscale heat exchanger, is a main component of a microchannel fuel processor that will hopefully enable fuel cell powered vehicles. Conventional heat exchangers are too large to be used in this application, nor can they deliver the kind of performance needed in this application. The microscale heat exchanger is also making possible a portable fuel cell power supply. This power supply could make batteries obsolete. It will have a longer run time than a battery of comparable weight. It could also be used in place of portable generators that operate with an internal combustion engine. These fuel cells would operate more quietly and with a greater efficiency than an engine driven generator. Problems with refueling a generator in a remote location could also be solved be this new portable fuel cell

The Al_2O_3 water nano fluids was formulated by Lee et al [10] without any chemical dispersants and performed experiments to show that Al_2O_3 water nanofluids have good suspension and dispersion characteristics and high thermal conductivities. The importance of micron size mechanical devices are emphasized both in commercial and scientific application [11,12]. Kandlikar et al[13]. also insisted the the need of micro system in for heat transfer enhancement in micro scale devices.

Jung-Yeul et al [14] have reported that the Nusselt number increases with increasing Reynolds number in laminar regime in his experimental study. Nanofluids have a higher single phase heat transfer coefficient, especially for laminar flow, due to increased thermal conductivity [15,16].

Microchannel heat exchangers are classified as micro, meso, compact and conventional heat exchanger based on channel diameters [17]. In this study the heat transfer characteristics of water / CuO flowing through serpentine MC and hydraulic diameter of 0.81mm is investigated.

2. Fabrication of Serpentine Shaped Micro Channel

The micro channel is fabricated using the material copper. The copper is chosen for its improved corrosion resistance, thermal conductivity and smooth surface finishing. The copper plates are faced to for its required thickness. The plate is grinded in a bed type surface-grinding machine in order to get a smooth surface. The machining is done on the surface of the bottom plate. The inlet and outlet sumps are machined using milling process, then the channels are cut on the surface of the bottom plate using EDM process according to the dimensions shown in the fig (1). The map of the microchannel with fin core section is presented in section (2). To have circulation of the working fluid the hole is drilled on the on the surfaces of the bottom plate connecting the inlet sump with inlet surface and the outlet sump with outlet surface respectively.

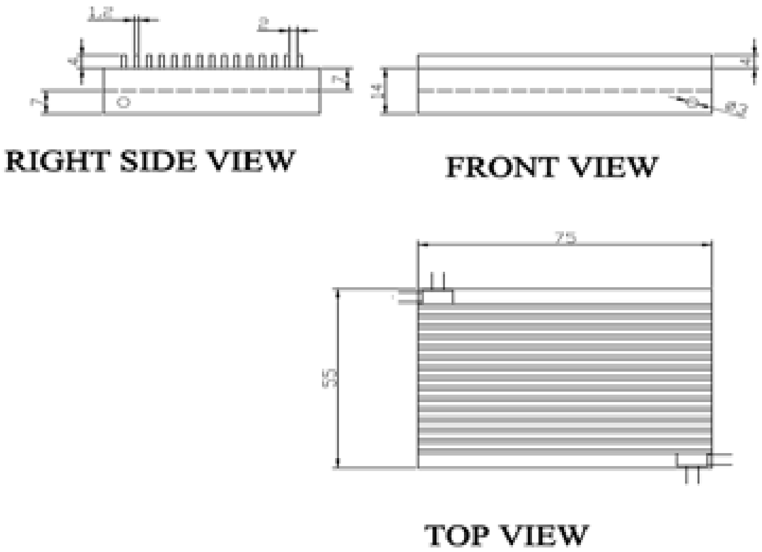

Fig. 1: Micro Channel test section.

Hydraulic pipe of standard dimension is brazed in the inlet and outlet surfaces of the microchannel, which is used as a connecting medium between the micro channel and the components of the experimental set-up. The square plate of side 75 mm and thickness 55mm is taken as top plate of the micro channel. Convection fins are machined on the top surface of the plate to enhance the heat transfer rate. This plate is used to cover the machined surface of the bottom plate. The EDM is considered to be a non-conventional machining technique. It is a process whereby the material is removed through the erosive action of electrical discharge (sparks) provided by a generator. With a precision EDM dimensional tolerances up to 0.5µm could be obtained.

A high speed EDM technique enables a dimensional tolerance up to 1.5 micro meter and a machining speed of 5 µ/ sec to be obtained. The smaller electrode used has a diameter of 30 micro meter, subsequent to this pioneering work. The interest in micro EDM machining remained sedate until micro-electronics era emanated. Even 3D shapes (that prove difficult for etching) are done easily with EDM (Reymaerts et al.,). Inlet and out conduits were attached together with the two plates and brazed in vacuum furnace at 5-10 torr and about 1000°C.

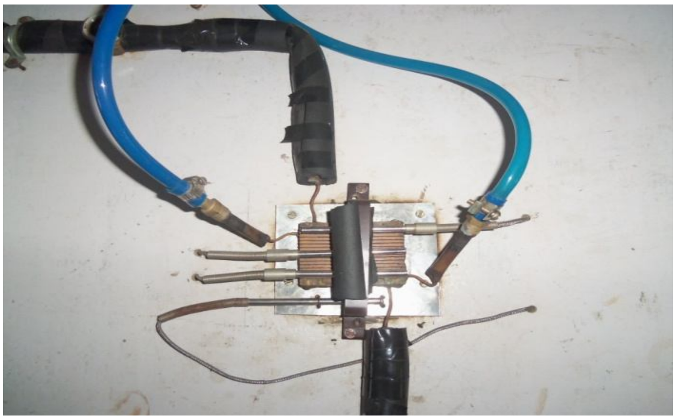

Fig. 2: Core section of the microchannel with fin

3. Experimentation

3.1. Preperation of Nanofluid

Gamma Copper oxide was used for the preperation of γ CuO Nanofluid with water as the Base material. γ CuO nano particales were dispersed in 3.5 lits of ultra pure double distilled water under sonification at different volume fraction say 0.01,0.02,0.03,0.1,0.2,0.3 and tested for the heat trasfer property of the material in the microchannel.

3.2.Characterisation of Nanofluid

Characterisation Analysis were carried out using Scanning Electron Microscope (SEM) and Energy dispersive Atomic X Ray(EDAX) .

3.3 Micro channel heat sink experimental setup

A schematic diagram of the experimental apparatus is shown in Fig. (3). The test loop consists of a Ultrasonic vibration Bath, Pump, Filter, Flow meter ,Micro-channel, Heater and Air cooled heat exchange. In the present study, CuO nanofluids are stored in the ultrasonic vibration bath. This bath acts as a reservoir and sonificator.A heater is fixed on the surface of the microchannel. A pump is attached between the bath and the microchannel to circulate nanofluids through the entire circuit. The unwanted micron size particle are removed using filters.

Flow meter is placed between the pump and micro channel. Fluid flow rate is controlled by the valve and it is placed between the pump and channel. The pressure gauges are fixed at the inlet and outlet of the micro channel and used to measure the pressure drop of the channel. When the nano fluid passes through microchannel, it absorbs some amount of heat supplied by the heater. The excess heat carried by the nano fluid is released when it passes through the air cooled heat exchanger Then the fluid moves to the bath and the cycle is repeated. The entire set-up is kept airtight in order to prevent any leakage of the fluid.

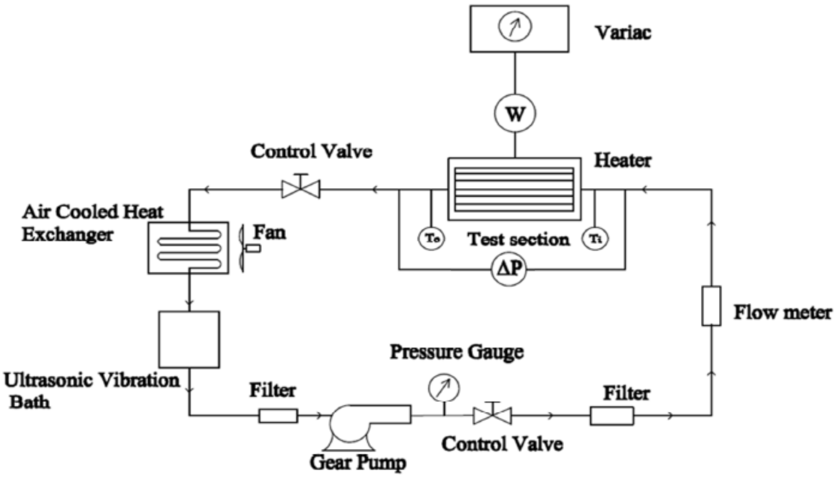

Fig. 3: Schematic diagram of the experimental setup.

4. Data Analysis and Processing

4.1 Thermophysical properties of nanofluids

Since we use nanofluids for the heat removal their thermo physical property and the governing equation involved are calculated using the following equation[18]

Density:

$$\rho_{nf}=(1-\varphi)\rho_{bf}+\varphi\rho_{p} \tag{1}$$

Heat capacity:

$$(\rho cp)_{nf}= (1-\varphi)(\rho cp)_{bf}+\varphi(\rho cp)_{p} \tag{2}$$

Thermal conductivity:

$$\kappa_{nf} = 3.59\ x\ 10^{-9}\ C_{p\ nf}\rho_{nf}\left(\frac{\rho_{nf}}{M_{nf}}\right)^{1/3} \tag{3}$$

Viscosity:

$$\mu_{nf}=\mu_{bf}(1 + 2{:}5)\ \varphi \tag{4}$$

4.2 Data processing

The Reynolds number is defined in the conventional way, $Re=\rho vd/\mu$. The velocity is calculated from flow rate based on the cross-sectional area of the channel. The velocity is evaluated using the mass flow rate and the equivalent diameter Dh=2 WH/ (W+H). The mass flow rate was evaluated based on the density at inlet condition.

The balance between the energy supplied and energy absorbed by the flowing liquid is established using the following equations:

$$Qs=V \times I \text{ (heat supplied)} \tag{5}$$

$$Q= m\ Cp_{nf}\ (Tout\text{–}Tin)_{nf} \text{ (heat absorbed)} \tag{6}$$

Experimental convective heat transfer coefficient and Nusselt number for nanofluid were calculated from the following equations: [19]

$$h_{(exp)}=\frac{Q}{A(Tw-Tm)} \tag{7}$$

$$Nu_{(exp)}=\frac{h_{(exp)}.D_h}{k_{nf}} \tag{8}$$

The liquid reference temperature T_m is arithmetic mean of the inlet temperature and outlet temperature, that is

$$T_m=\frac{T_{in}+T_{out}}{2} \tag{9}$$

The mean heat flux q relative to the base plate area A is as follows

$$q=h_{(exp)}.(T_w-T_m) \tag{10}$$

In general, for total length of the micro channel with 'n' vertical passage and (n-1) circumferential passage is given by

$$L_{ch}=nl+(n-1)(2\pi r)+2r \tag{11}$$

The hydraulic performance of the heat sink can be evaluated by means of the friction factor
defined as [20]

$$f=\frac{\Delta p}{2\rho_{nf}}\frac{D_h}{u_m^2 L_{ch}} \tag{12}$$

Experimental friction factor is compared with the theoretical values obtained using Hagen-
Poiseuille equation given by

$$f=\frac{64}{R_e} \tag{13}$$

Reynolds and prandtl number are calculated using following equations:

$$Re=\frac{\rho_{nf}u_m D_h}{\mu_{nf}} \tag{14}$$

$$Pr_{nf}=\frac{\mu_{nf}C_{pnf}}{K_{nf}} \tag{15}$$

Experimental heat transfer coefficient is compared with the theoretical heat transfer coefficient values obtained using Dittus-Boelter given by [21]

$$Nu\,(th)=0.024Re^{0.8}.Pr^{0.4} \tag{16}$$

$$N_u\,(th)=\frac{h_{(th)}D_h}{k} \tag{17}$$

$$h\,(th)=\frac{N_{u(the)}.k}{D_h} \tag{18}$$

Thermal resistance is calculated as, $R=\frac{T_w-T_m}{q}$ (19)

5. Results and Discussion

5.1 SEM&EDAX Analysis

The Fig.(4) SEM analysis revealed that the CuO particles were spherical in nature with a diameter of around 15 nm.Fig.(5) EDAX report conformed the presence of Copper and oxygen with the weigh % of 50.12 and 49.88 respectively

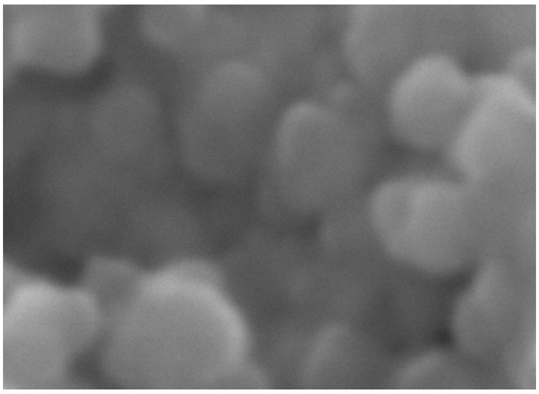

Fig. 4: SEM of CuO particle

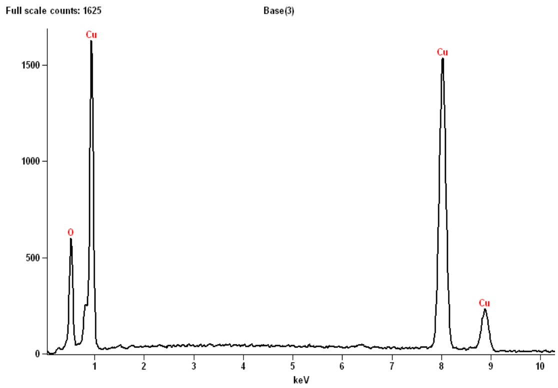

Fig. 5: EDAX of CuO particle

The thermo physical properties of 0.3% CuO / water nanofluid were estimated as follows:

Density=2673.98 kg/m3, Heat capacity=1659.48 J/kg-K, Thermal conductivity=0.9936 W/mK, Viscosity=0.027475 .

5.2. Pressure drop analysis

The pressure drop is calculated experimentally for the CuO water nanofluid for the serpentine shaped microchannel to investigate two caharacteristics of the nanofluids. Friction factor obtained for the microchannel heat sink using the pure water (φ=0.01 to 0.3vol. %) as well as nanofluid (φ=0.01 to 0.3vol.%) as coolant are done Substituting the measured pressure drop into equation (13), the Darcy friction f =64/Re is calculated.

5.3. Heat transfer analysis

The convective heat transfer coefficient shown in fig 6. Clearly states that the heat transfer characteristics of CuO nanoparticle when suspended in the water has enhanced heat transfer property in the micro channel heat sink. All though the volume fraction of nano particles is very low range from 0.01 to 0.3vol.%. The convective heat transfer coefficient of water-based CuO nanofluids increases with volume fraction of CuO nano particles. Similar finding was reported in previous experiment work [22].

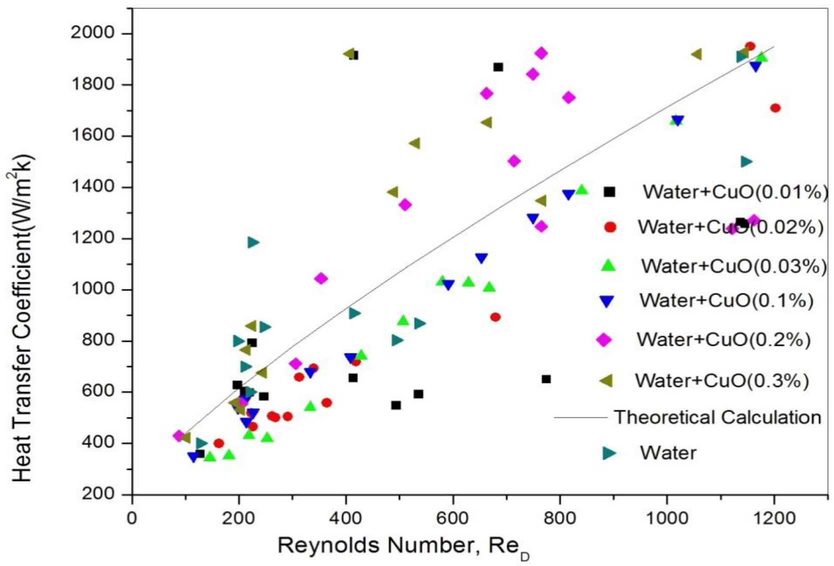

Fig. 6. Experimental heat transfer coefficient is compared with the theoretical heat transfer coefficient values obtained using Dittus-Boelter, shown in table (1).

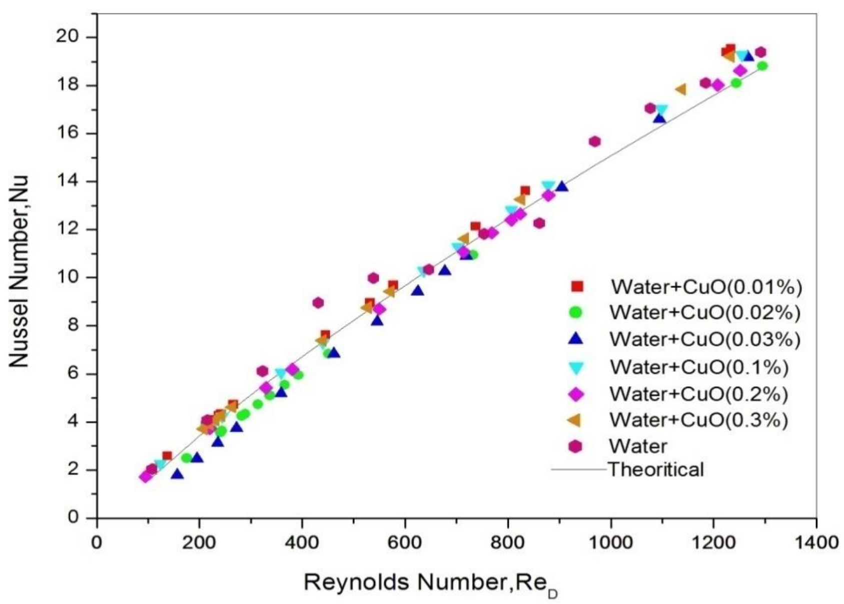

Fig. 7: Comparison of experimental Nusselt with the theoretical values obtained using the Dittus-Boelter, shown in Table (1).

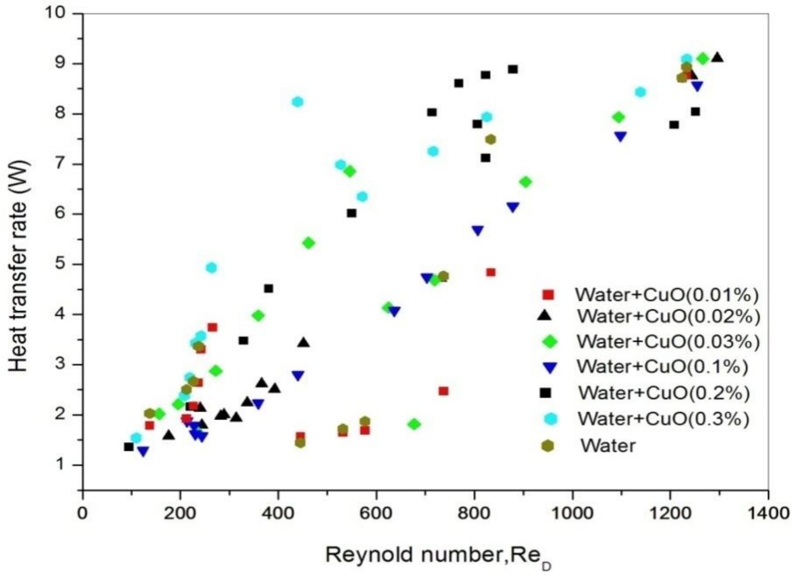

Fig. 8: Total heat transfer versus Reynolds number and concentration of nanofluid

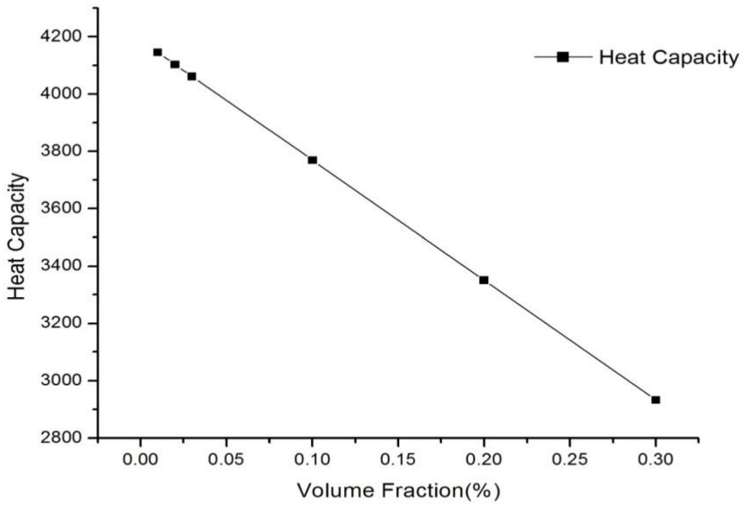

Fig. 9: Heat capacity versus volume fraction concentration of nanofluid

6. Conclusions

The heat transfer characteristics of serpentine shaped microchannel heat sink with CuO/water nanofluid is experimented and its enhanced thermal conductivity is compared with the base fluid. Based on the heat transfer enhancement and fluid flow characteristics the various plots showing the relation is plotted for the conclusion. The flow and heat transfer characteristics of the heat sink cooled by 0.01,0.02,0.03, 0.1,0.2

and 0.3 vol % nanofluids have been presented. The following conclusions are drawn from this research:

The theoretical results of the Darcy friction factor correlation for the fully developed laminar flow has good coordination due to pressure drop for the CuO water nanofluid when measured.

The convective heat transfer coefficient for the low volume percentage of CuO nanoparticles there is considerable enhanced thermal conductivity.

Thermal performance of nanofluids in all concentration study showed better efficiency than pure water. Temperature distributions on the serpentine MC were very much lower using nanofluid compared to pure water.

Thermal Resistance of the MC heat sink was decreased when using CuO. When the volume fraction is increased in the water-CuO ranges from 0.01 - 0.3, the nanofluid thermal conductivity increases considerably and also heat transfer performance also been enhanced, which is shown in fig.(8) and fig.(9) The experimental results showed that of MC load with nanofluids CuO/water as coolant proved its potential as an alternative working fluid compared to conventional pure water.

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