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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF FORCED CONVECTIVE HEAT TRANSFER COEFFICIENT IN NANOFLUIDS OF AL_2O_3/WATER AND CuO/EG IN A SERPENTINE SHAPED MICROCHANNEL HEAT SINK

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ABSTRACT

Nanofluid is the suspension of solid nanosized particles in conventional fluids. The important character of such fluids is the enhanced thermal conductivity, in comparison with base fluid without considerable alteration in physical and chemical properties. In this investigation nanofluids of Al_2O_3/water and CuO/Ethylene glycol were prepared separately. The effect of forced convective heat transfer coefficient was calculated using serpentine shaped microchannel heat exchanger. Furthermore we calculated the forced convective heat transfer coefficient of the nanofluids using theoretical correlations in order to compare the results with the experimental data. The heat transfer coefficient for different particle concentration and temperature were analysed using forced convection heat transfer using nanofluids. The findings indicate considerable enhancement in convective heat transfer coefficient of the nanofluids as compared to the basefluid. The results also shows that CuO/EG nanofluid has increased heat transfer coefficient compared with Al_2O_3/water and base fluids. Moreover the experimental results indicate there is increased forced convective heat transfer coefficient with the increase in nanoparticle concentration.

Keywords: Forced convection, microchannels, pressure drop, heat transfer etc.

1. INTRODUCTION

With the developments in thermal sciences and thermal engineering many experiments has been undergone for the enhanced heat transfer. The recent developments in this heat transfer improvement is the addition of solid materials into the liquid medium. In this suspended liquids the flow media itself is a controlling factor of heat transfer performance, the solid particles suspended in the base fluids change the transport properties, flow and heat transfer features of the liquid[1]. The term ‘‘nanofluid’’ is applied to a suspension of solid, nanometer-sized particles in conventional fluids; the most prominent features of such fluids include enhanced heat characteristics, such as convective heat transfer coefficient and thermal conductivity in comparison to the base fluid without considerable alterations in physical and chemical properties. The improved heat transfer in a system has the benefit of decreased energy expenditure, decreased raw materials input, reduced size of equipment, and consequently, reduced expenses and increased system efficiency.

The technological problems in microcahnnels when using micro or millimeter sized particles is quickly settling down of the solid particles, clogging in the path way increasing pressure drop considerably and Furthermore, the abrasive actions of the particles cause erosion of components and pipe lines [2].This problems has overcome by the nano sized particles and its characteristics. Choi [3] was the first to employ the nanometer-sized particles in conventional fluids and showed considerable increase in the nanofluid thermal conductivity. Lee et al. [4] investigated experimentally for the suspension of 4.0% volume 35 nm CuO particles in ethylene glycol and observed 20% increase in thermal conductivity. Xuan and Li [5] have investigated that 35 nm Cu/deionized water nanofluid flowing in a tube with constant wall heat flux showed that the ratio of the Nusselt number for the nanofluid to that of pure water under the same flow rate, varies from 1.05 to 1.14 by increasing the volume fraction of nanoparticles from 0.5% to 1.2%, respectively. Xuan and Li [1] has also reported that Cu/water nanofluid under constant wall heat flux in turbulent flow has proven that convective heat transfer enhancement of nanofluid may be related to thermal conductivity increase or random movement and dispersion of nanoparticles in nanofluid. This lead to the proposal of new correlation by dispersion model, considering the effect of volume fraction and size effect of nanoparticle for the enhancement.

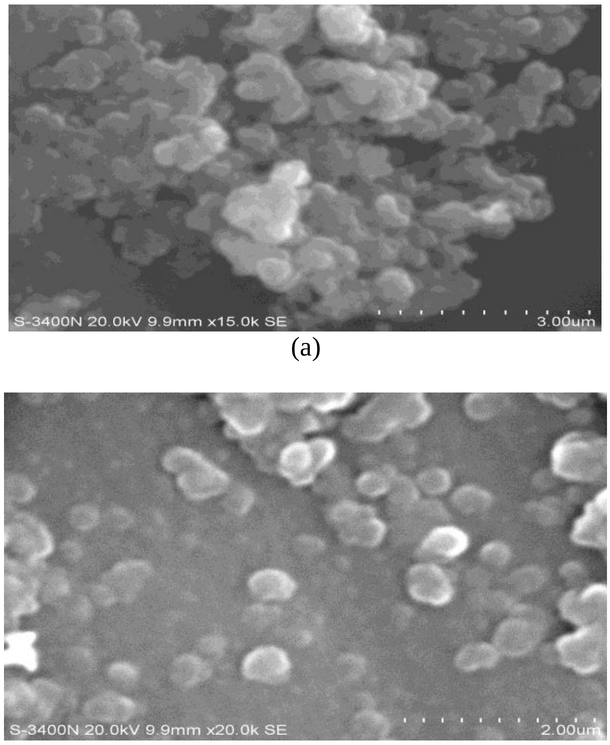
Wen and Ding [6] have studied Al_2O_3/water nanofluid heat transfer in laminar flow under constant wall heat flux and proved the increase in heat transfer coefficient with Reynolds number and nano particle concentration particularly at the entrance region. The research highlighted the thermal developing length for the nanofluid is greater than the water. The reason for the enhanced thermal conductivity is due to Brownian motion of the nanoparticle resulting decreased thermal boundry layer and non uniform distribution of thermal conductivity. Cesare Biserni et al. [7] investigated the natural convection of Al_2O_3/water in an heterogeneous heating of square cavity which reveals relation between Nusselt number and Rayleigh number Palm et al. [8] through numerical investigation of laminar flow heat transfer of Al_2O_3/ethylene glycol and Al_2O_3/water nanofluids in a radial flow system there remarkable improvement in heat transfer rate. The results also concluded wall shear stress increased with nanoparticle concentration and Reynolds number. Putra et al. [9] have reported that the decrease in heat transfer rate in Al_2O_3/water and CuO/water is due to nanoparticle settling and the velocity difference between nanoparticle and base fluid.

The aim of the present investigation is to study the stability of nanofluids and heat and their heat transfer characteristics. In this research work the nanofluids Al_2O_3/water and CuO/EG were prepared separately. The effect of forced convective heat transfer coefficient in turbulent flow was calculated using a serpentine shaped microchannel heat sink made of copper material. The test was conducted for the different concentration of nanoparticle and operating temperatures. The theoretical correlations were calculated the forced convective heat transfer coefficient of the nanofluids and compared the results. The experiments were conducted in two steps the first the nanofluids preparation and stabilization and second step is the subjecting the prepared nanofluids in heat transfer process which is the thermal cycle of microchannel heat sink.

2. NANOFLUID PREPARATION AND STABILIZATION

The process of preparation of nanofluid and stabilization is an important activity since extracting the benefits of nanoparticle in thermal cycle needs proper preparation and stabilization. Poorly prepared nanofluids results in biphasic heat transfer (i.e. solid–liquid). Particle instability results in particle fouling in reservoir, pipes, pumps and other equipment of thermal cycle, as well as reduced pressure, all of which are considered undesirable factors in our experiment.

The nanoparticles used in this study were aluminum oxide and copper oxide nanoparticles of approximately 15 nm in diameter and 95% purity. As for the Al_2O_3/Water nanofluid, samples of 0.1% to 0.3%, fluid were prepared without surfactants solely with magnetic stirring for 1 h and subsequent ultrasonic irradiation for 2 h. These samples proved highly appropriate in terms of homogenous dispersion and long term stability. As for the CuO/EG nanofluid, samples of 0.1% to 0.3% weight copper oxide in base fluid (EG) were prepared using the surfactant sodium dodecyl sulfate (SDS) alongside magnetic stirring for 1 h and subsequent ultrasonic irradiation for 2 h. These samples proved appropriate for a cyclic system in terms of homogenous dispersion and long term stability. The fig 1 (a) and (b) shows the SEM image of CuO and Al_2O_3 nanofluid. The particles are homogenously dispersed throughout the basefluid in an acceptable fashion.



(a) (b)

Figure 1. SEM image of (a) CuO/EG nanofluid and (b) Al_2O_3/water nanofluid

3. MICRO CHANNEL FABRICATION

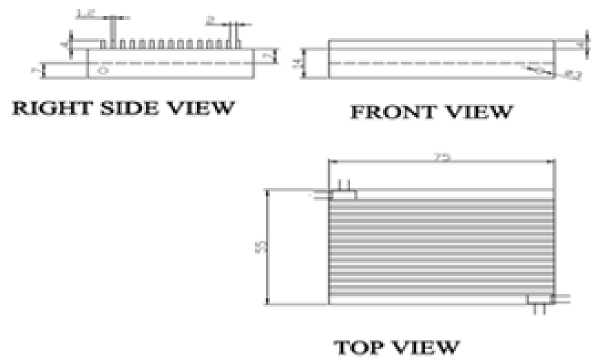


Figure 2. Microchannel test section

Copper is used as a material for fabricating the micro channel. This material is selected for its greater hardness, thermal conductivity and smooth surface finishing. Initially the plates are faced to get the 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. As the first process inlet and outlet sumps are machined using milling process and then, channels are cut on the surface of the bottom plate using EDM process according to the dimensions shown in Fig. (2).The map of the microchannel with fin core section is presented in Fig. (2).In order to circulate the working fluid into the micro channel a drilling process is made on the surfaces of the bottom plate connecting the inlet sump with inlet surface and the outlet sump with outlet surface respectively. 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 0.5 µm 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 1000ºC.

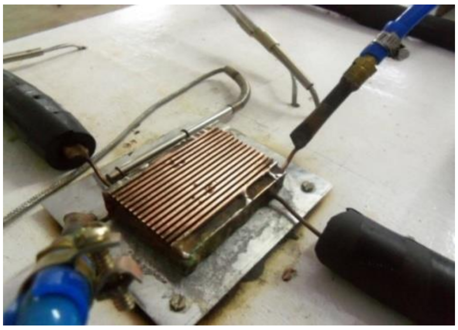


Figure 3. Core section of the microchannel with fin

4. MICRO CHANNEL HEAT SINK EXPERIMENTAL SETUP

A schematic diagram of the experimental apparatus is shown in Fig. (4). 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 and Al_2O_3 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.

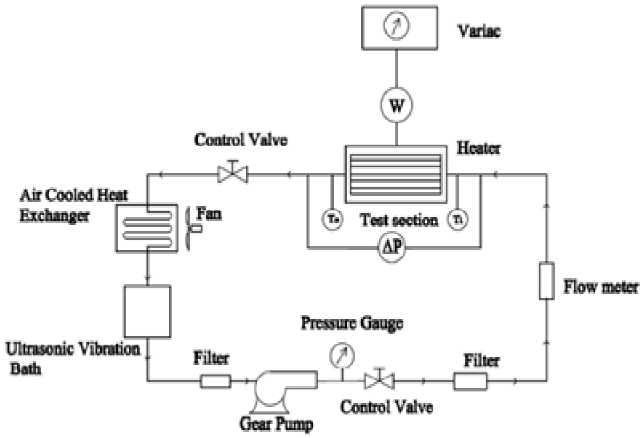


Figure 4. Schematic representation of experimental setup

5. DATA ANALYSIS AND PROCESSING

5.1 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[13].

Density: $\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_p$ (1)

Heat capacity:

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

Thermal conductivity:

$\kappa_{nf} = \left[\frac{kp+2kbf+2(kp-kbf)\varphi}{kp+2kbf-2(kp-kbf)\varphi}\right]k_{bf}$ (3)

Viscosity: $\mu_{nf} = \mu_{bf}(1 + 2.5)\,\varphi$ (4)

5.2 Data processing

The Reynolds number is defined in the conventional way, Re=ρvd/µ. 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 D_h = 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 x I (heat supplied) (5)

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

Experimental convective heat transfer coefficient and Nusselt number for nanofluid were calculated from the following equations: [10]

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

$$\text{Nu}_{(exp)} = \frac{h_{(exp)}.D_h}{k_{nf}} \quad (8)$$

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

$$T_m = \frac{T_{in}+T_{out}}{2} \quad (9)$$

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

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

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

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

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

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

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

$$f = \frac{64}{R_e} \quad (13)$$

Reynolds and prandtl number are calculated using following equations:

$$Re = \frac{\rho_{nf} u_m D_h}{\mu_{nf}} \quad (14)$$

$$Pr_{nf} = \frac{\mu_{nf} C_{pnf}}{K_{nf}} \quad (15)$$

Experimental heat transfer coefficient is compared with the theoretical heat transfer coefficient values obtained using Dittus-Boelter given by [12]

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

$$N_u\text{(th)} = \frac{h_{(th)} D_h}{k} \quad (17)$$

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

Thermal resistance is calculated as,

$$R = \frac{T_w - T_m}{q} \quad (19)$$

6. RESULTS AND DISCUSSION

6.1 Pressure drop analysis

The pressure drop is calculated experimentally for the Al_2O_3/water and CuO ethylene glycol nanofluid for the serpentine shaped microchannel to investigate two caharacteristics of the nanofluids. Friction factor obtained for the microchannel heat sink using the above nanofluid (φ=0.01 to 0.3vol.%) as coolant are done. As shown in fig 7. And in fig 10. Substituting the measured pressure drop into equation (13), the Darcy friction
f =64/Re is calculated

6.2. Heat transfer analysis

The convective heat transfer coefficient shown in fig 5,6. Clearly states that the heat transfer characteristics of CuO nanoparticle when suspended in the ethylene glycol 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 ethylene glycol -based CuO nanofluids increases with volume fraction of CuO nano particles. The results which have been obtained is shown in the graph plots below and it strengthens the fact that nanoparticle has significant role in the thermal conductivity and provides opportunities for more technological improvement in the electronic cooling and invention of sophisticated electro products[13]. While comparing the nusselt number and Reynolds number for the prepared nanofluids as in fig 8. The values of CuO/Ethylene glycol is higher than the Al_2O_3/water which indicates the property of the fluids.

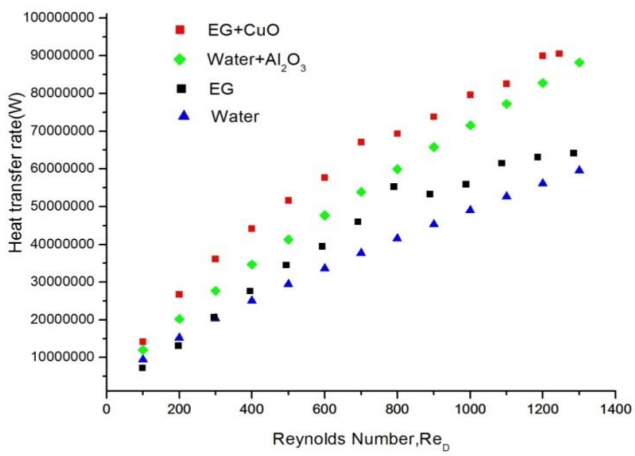


Figure 5. Camparison of heat transfer rate of nanofluid with the Reynolds number

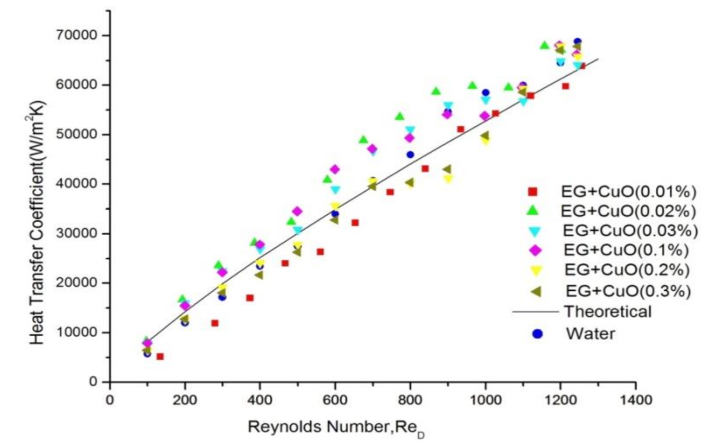


Figure 6. Heat transfer coefficient Vs Reynolds number for CuO/EG for different concentration and theoretical result

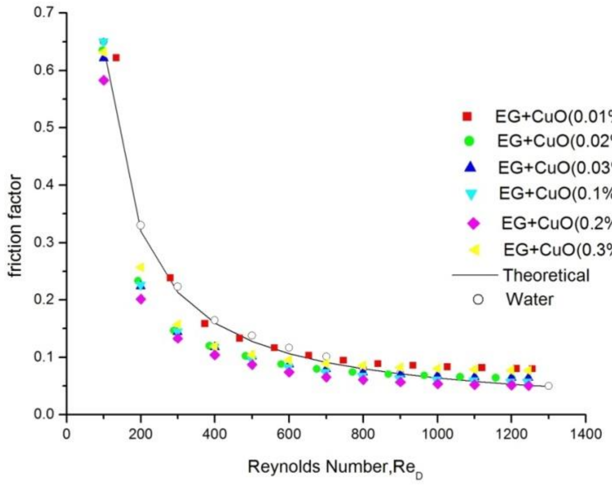


Figure 7. Friction factor Vs Reynolds number for CuO/EG for different concentration and theoretical result

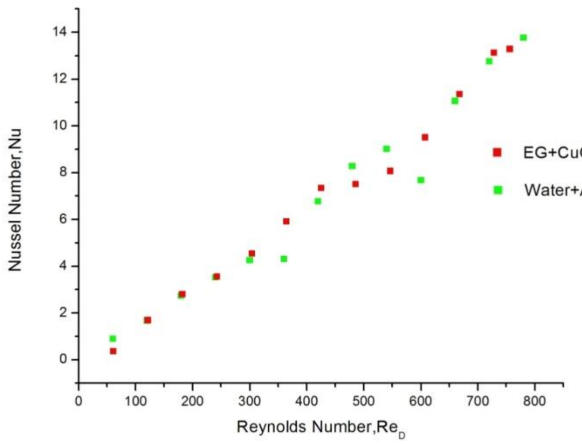


Figure 8. Nusselt number Vs Reynolds number for CuO/EG and Al_2O_3/water

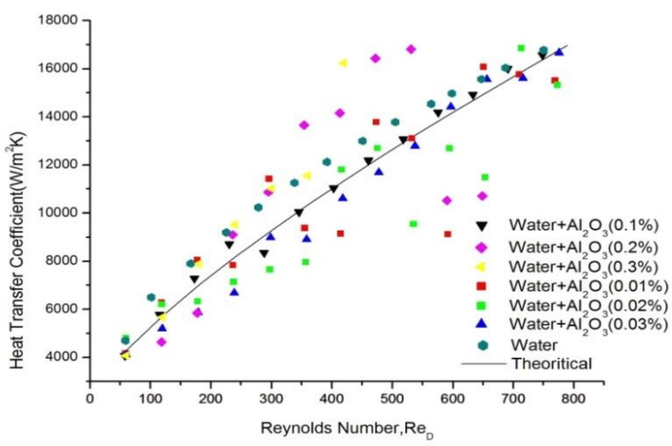


Figure 9. Heat transfer coefficient Vs Reynolds number for Al_2O_3/water for different concentration and theoretical result

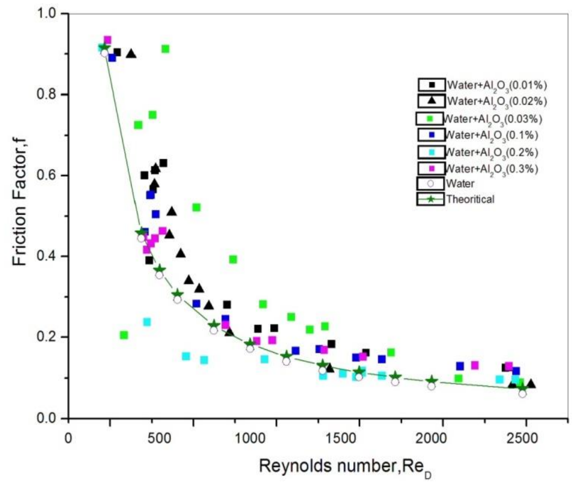


Figure 10. Friction factor Vs Reynolds number for Al_2O_3/water for different concentration and theoretical result

7. CONCLUSIONS

In this study, ''Al_2O_3/water'' and ''copper oxide/ethylene glycol'' nanofluids were prepared at various concentrations, each with its own particular stabilizing method. Subsequently, their heat characteristics were evaluated through serpentine shaped microchannels heat sink the results as follows:

- The results shows there is increase in heat transfer coefficient of nanofluids CuO/ethylene glycol and Al_2O_3/water when compared with their base fluids.
- The results also proves that there is enhanced heat transfer coefficient of CuO/Ethylene glycol compared with Al_2O_3/water nanofluid. The heat transfer coefficient of CuO/Ethylene glycol for 0.3% volume fraction is 71630.4981 W/m^2K. The heat transfer coefficient of Al_2O_3/water for 0.3% volume fraction is 64895.0699 W/m^2K.
- The experimental values were compared with theoretical data. 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 ethylene glycol nanofluid when measured. The convective heat transfer coefficient for the low volume percentage of CuO nanoparticles there is considerable enhanced thermal conductivity.
- Thermal Resistance of the MC heat sink was decreased when using CuO. When the volume fraction is increased in the ethylene glycol -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 the graph. The experimental results showed that of Microchannel load with nanofluids CuO/ ethylene glycol as coolant proved its potential as an alternative working fluid compared to ethylene glycol base fluid and Al_2O_3/water nanofluid.
- The enhanced heat transfer coefficient for the CuO/Ethylene glycol due to the higher viscosity and density of the basefluid ethylene glycol.
- The serpentine shape also favors for the enhanced heat transfer rate. This is due to the increased Brownian

motion of the nanoparticle while passing through the serpentine shaped with fins channel.

- From this experimental work with nanoparticles for the use of heat transfer the design of the microchannel duct is an important finding and design factor for the enhanced heat transfer, this provides way for the future researchers in heat transfer enhancement.

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NOMENCLATURE

A	Cross section area (m^2)
D_h	Hydraulic diameter (mm)
H	Channel height (mm)
h	Convective heat transfer coefficient(W/m^2 K)
k	Thermal conductivity (W /mK)
L	Test section length (mm)
l	Length of the vertical passage (mm)
L_{ch}	Total channel length (mm)
m	Mass flow rate (kg/s)
N	Number of vertical passage
Nu	Nusselt number
Pr	Prandtl number
q	Actual heat flux (W/m^2)
Q_s	Heat supplied (W)
Q	Heat transfer (W)
r	Radius of the circular passage (mm)
R_e	Reynolds number
T	Temperature (K)
u	Velocity (m/s)
W	Channel width (mm)
f	Friction factor
$(C_{p)nf}$	Nanofluid heat capacity (J/kgK)
ρ_{bf}	Density of base fluid (kg/m^3)
ρ_p	Density of particle (kg/m^3)
$(C_p)_p$	Particle heat capacity (J/kgK)
K_p	Thermal conductivity of particle (W /mK)
K_{bf}	Thermal conductivity of base fluid (W /mK)
μ_{nf}	Viscocity of nanofluid (kg/m^2 s)
μ_{bf}	Viscocity of basefluid (kg/m^2 s)

Greek symbols

μ	Dynamic viscosity (kg/m^2 s)
Δp	Pressure drop (pa)
ρ	Density(kg/m^3)
φ	Volume fraction of nanoparticles (%)

Subscripts

b_f	Base fluid
exp	Experimental
in	Inlet
m	Mean
n_f	Nanofluid
out	Outlet
p	Particle
th	Theoretical
w	Wall

Abbreviation

Al_2O_3	Aluminium Oxide
CuO	Copper Oxide
EG	Ethylene glycol