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Experimental Thermal Investigation of CuO-W Nanofluid in Circular Minichannel

Asif Afzal*, Mohammed Samee A.D, Abdul Razak R.K

Department of Mechanical Engineering, P.A. College of Engineering, Visvesvaraya
Technological University, Mangaluru, India
(asif.afzal86@gmail.com)

Abstract

This paper presents an experimental comparative thermal analysis of CuO-W nanofluid in circular minichannels. Under steady state forced convection and constant heat flux of 3.4 KW/m^2 CuO-W nanofluid and water are passed through the minichannel. The flow rates chosen are 0.4 lpm (litre per minute), 0.6 lpm, 0.8 lpm and 1 lpm and with hydraulic diameter of 2mm of the minichannel. Variation in Nusselt number (Nu), Convective heat transfer coefficient (h), friction factor, pressure drop and pumping power along with flow rates for CuO-W nanofluid are compared with water. For all the flow rates considered in present investigation, an increase in all the thermal parameters is observed. % enhancement in actual heat transfer rate is upto 89%, 20% for convective heat transfer coefficient and 26% in case of Overall heat transfer coefficient are obtained compared to water. However, the pumping power required for CuO-W nanofluid is more compared to water.

Key words

CuO, Water, Nanofluids, Circular minichannels, Heat transfer enhancement.

1. Introduction

For cooling several electronic devices heat sinks are employed. In many engineering applications and in biomedical devices a lot of interest is growing due to their enhanced heat transfer characteristics. Minichannel heat sink serves as a means of cooling for several devices. Due to this, attention of researchers is increasing for their application in automobile, aerospace, bioengineering, refrigeration and electronic cooling [1],[2]. To enhance the heat transfer phenomenon in minichannels, nanoparticles are mixed with conventional fluids like water and circulated through the channels. The obtained nanofluid is passed through the minichannels which results in great enhancement of heat transfer rate [3],[4]. Many nanofluids prepared using nanoparticles like Al_2O_3, CuO, TiO_2, SiO_2, MWCNT etc., are studied by various researchers for their application in different heat sinks and heat exchangers [5]-[7].

Al_2O_3 nanoparticles suspended in water/ethylene glycol as base fluid was experimented in minichannel with 0.1-0.25% VC (volume concentration) [9], Re 133 to 1515 [10], 0.1 & 0.5% VC [11], 0-3% VC [12] having different cross sectional channels. Significant heat transfer enhancement (HTE) is reported in all the cases mentioned. Al_2O_3 and TiO_2 with 0.8-4% VC in water [13] and Re 125-20000 [14] was separately studied and reported upto 71% THE. TiO_2 and SiC [15], TiO_2, [16], Diamond, CuO, SiO_2 [17] are used in different case studies and all reported good improvement in convective heat transfer coefficient.

However, experimental study of CuO-W nanofluid in circular minichannel is not reported in the previous works. Hence this work is intended to analyze the heat transfer characteristics of minichannel maintained at constant heat flux using CuO-W as nanofluid for 0.02% volume concentration.

2. Experimental Methodology

2.1 Nanofluid Preparation and Experimental Setup

The nanoparticles are purchased form Sigma Aldrich chemicals Limited, India. The water was used as a base fluid for this study. The CuO-Water nanofluids of 0.02% volume concentrations were prepared by dispersing CuO nanoparticles in water. The solution was sonicated continuously for 1 hour using a probe sonicator to disperse the nanoparticle uniformly. Following this, the nanofluids was stirred continuously to obtain uniform dispersion of nanoparticles in base fluid. Figure 1 shows CuO-W nanofluid preparation.

2.2 Relations Used

The following Equations 1-8 were used to estimate the different important thermal parameters of the minichannel heat sink.

Actual heat transfer: $q = m_f C_p \left(T_{c,o} - T_{c,i}\right)$ (1)

Reynolds number: $R_e = {}^{\rho D_h v}/_{\mu}$ (2)

LMTD: $\Delta T_{lmtd} = {}^{(\Delta T_2 - \Delta T_1)}\Big/_{ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}$ (3)

where $\Delta T_2 = \Delta T_b - \Delta T_{h,o},\ \Delta T_1 = \Delta T_b - \Delta T_{c,i}$

Nusselt number: $Nu = 0.027Re^{0.8}Pr^{0.33}\left(\frac{\mu}{\mu_w}\right)^{0.14}$ (4)

Heat transfer coefficient: $h = {}^{N_u k}/_{D_h}$ (5)

Friction factor: $f = 0.184Re^{-0.2}$ (6)

Pressure drop: $\Delta P = f\rho\left({}^{L}/_{D_h}\right)\left({}^{v^2}/_{2}\right)$ (7)

Pumping power: $P = \Delta P f v$ (8)

Copper oxide nanoparticles of size <50nm

CuO-Water nanofluids of 0.02%wt concentration

Sonication process of CuO-Water nanofluids

Fig.1. CuO Nanoparticles and Its Preparation for Nanofluids

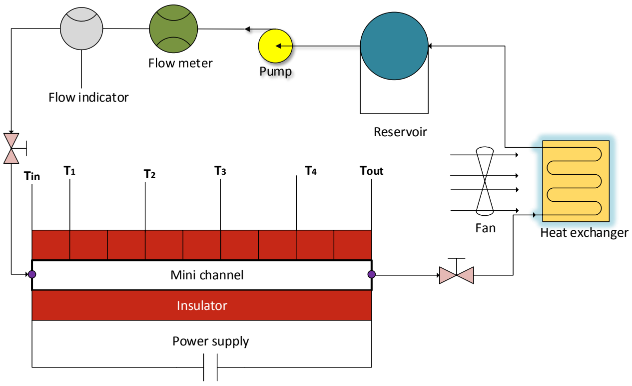

Fig.2. Experimental Setup of Minichannels

3. Results and Discussions

CuO nanoparticles of volume concentration 0.02% suspended in water as base fluid is used to analyse the thermal performance of circular minichannel for four different flow rates of 0.4 lpm, 0.6 lpm, 0.8 lpm and 1 lpm. The values of temperature are recorded after reaching a complete steady state under transition flow conditions. For each flow rate three trails were taken which consumes atleast 3 hours of time under a constant heat flux of 3.4 KW/m^2. Water was also circulated for the same flow rates to compare the results of CuO-W nanofluid.

The figure 3 shows the variation of Nu with flow rate at fully developed flow condition, we observe that as the flow rate increase the Nu also increases. This is mainly due to increase in velocity of fluid which further increases the convective heat transfer coefficient. CuO-W nanofluid have shown an increase in Nu for all flow rates except at 0.4lpm compared to water. As CuO nanoparticles have enhanced heat carrying capacity and thermal conductivity leading to improved heat transfer parameters like Nu and convective heat transfer coefficient as shown in Figure 4.

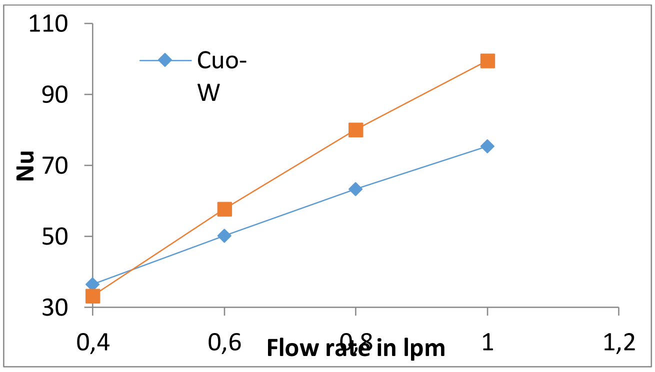

Fig.3. Variation in Nu for Variation in Flow Rates

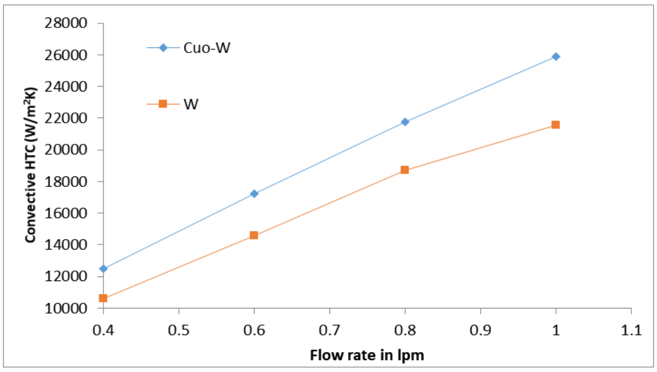

Fig.4. Improvement in Convective HTC for Variation in Flow rates of CuO-W

The Figure 4 shows the different major parts of the heat sink used for the existing study. Rotometers are used as flow meters here and they provide simple and efficient readings of flow rates. T-type (copper-constantan) thermocouple having a sensitivity of 43 µV/°C is used to measure the temperature of the flowing nanofluid at the inlet and exit of minichannel as they are suitable for a range of -220°C to 330 °C. K-type thermocouples are placed at several points on the channel to measure the channel surface temperature. They have range of about -220°C to 1400°C and are cheap. Electric heater employed is film heater which transforms alternating current into heat based on the principle of joule heating effect. To avoid any kind of transfer of heat from the surface of minichannel setup, it is insulated carefully with asbestos. A mini-pump is placed to supply the nanofluid from the reservoir to the heat sink. A heat exchanger is placed immediately after the flow of nanofluid from the minichannel in order to obtain the constant inlet temperature of the fluid. The minichannels are made of split aluminium plates of 2mm hydraulic diameter size circular channels. For the above-mentioned set-up, the nanofluid after sonification (achieved using probe sonicator) for 90 minutes to have a uniform suspension of CuO in water is pumped from the reservoir through the flow regulating valves. At the inlet of the minichannel, the temperature is measured and then allowed to pass through the channel so that it can carry heat from it. At different points of the minichannel, temperature is measured once the flow attains steady state. At the exit, again the temperature is recorded and made to pass through the heat exchanger so as to maintain the flowing fluid temperature at constant range.

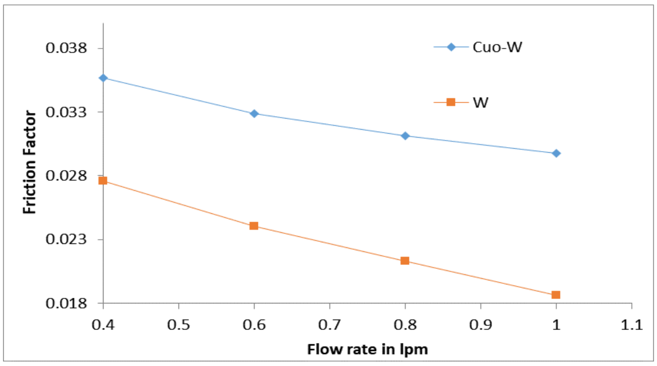

Fig.5. Friction Factor vs Different Flow Rates of CuO-W and Water

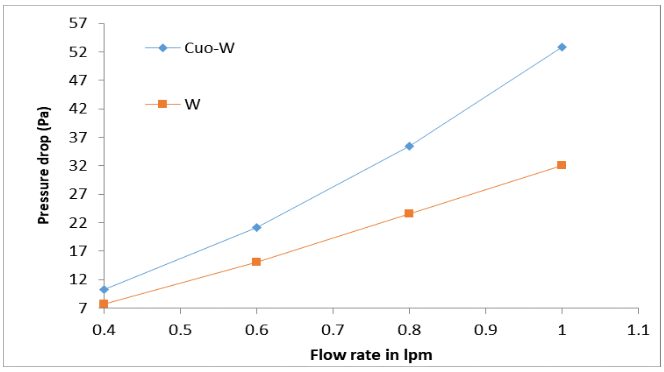

Fig.6. Pressure Drop vs Different Flow Rates of CuO-W and Water

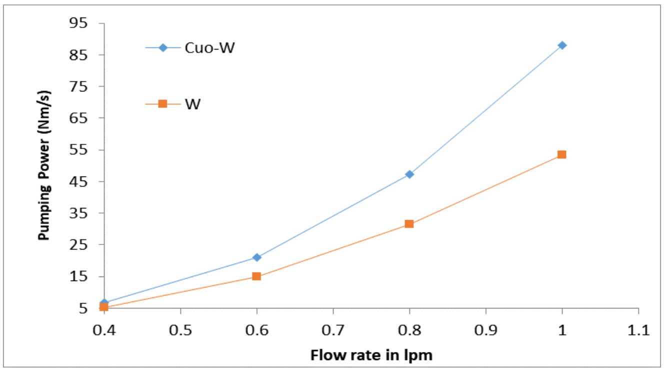

Fig.7. Pumping Power vs Different Flow Rates of CuO-W and Water

In Figure 5-7 depicts the change in friction factor, pressure drop and pumping power with flow rates. It is seen that with increase in flow rate the friction factor, pressure drop and pumping power also increases. It is known fact that the velocity and pressure are inversely proportional to each other in a flowing fluid, as the velocity of the fluid increases the pressure decreases which leads to overall drop of pressure throughout the length of the channel. The maximum variation in all the parameters considered are gradually increasing with flow rate.

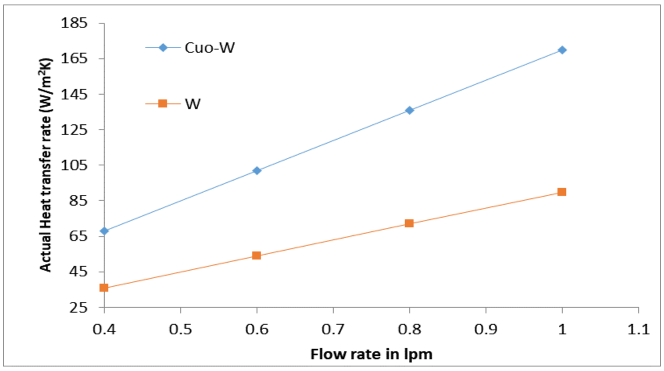

Fig.8. Actual Heat Transfer Rate Improvement along with Increase in Flow Rate

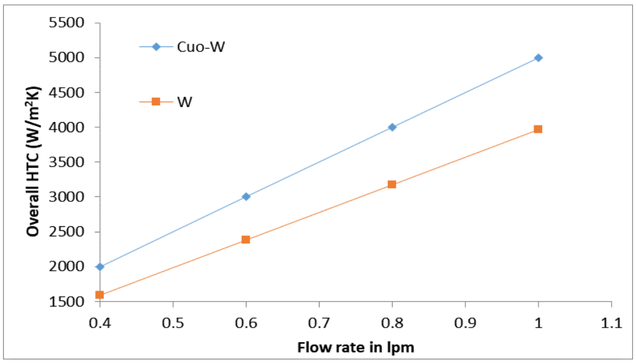

Fig.9. Overall HTC for CuO-w and Water

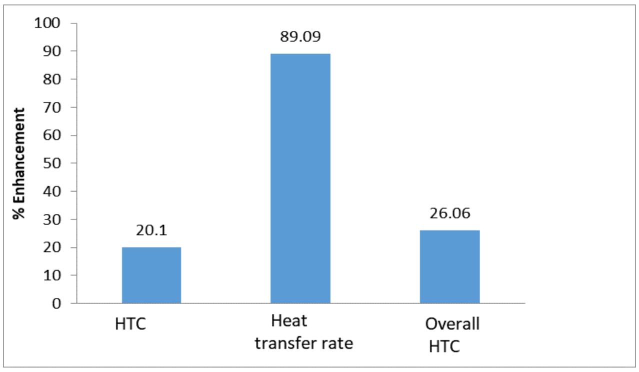

Fig.10. %Enhancement of Different Parameters at Flow Rate of 1 lpm Compared to Water

The parameters such as Convective HTC (Figure 4), Actual heat transfer rate (Figure 8) and Overall HTC (Figure 9) are gradually increasing with increase in flow rate. We can see that at 1 lpm these parameters are showing maximum variation compared to water. On the other hand, the energy consuming parameter pumping power has also increased which is due to increased viscosity of the nanofluid due to presence of CuO nanoparticles.

From figure 10 % enhancement are shown compared to water at a flow rate of 1 lpm. It can be quickly noticed the difference obtained. This improved thermal parameters are obviously at the cost of increased pumping power. Upto 89% actual heat transfer rate has enhanced, which is a sign of ability of CuO-W nanofluid to be used in heat sinks for cooling various devices.

Conclusion

An experimental study has been carried out on comparative heat transfer analysis of circular minichannels subjected to CuO-W nanofluid. The experiments were conducted for constant heat flux under steady state transition flow with forced flow conditions. During the time of experiments the following concluding remarks were disclosed.

- With increase in the flow rate the convective heat transfer coefficient increases and it is maximum in case of CuO-W nanofluid compared to water.
- For CuO-W nanofluid the amount of pumping work required is more compared to water.
- Even for small percentage of CuO nanoparticles suspension in base fluid can improve and enhance the heat transfer capability of fluid.
- % enhancement in actual heat transfer rate is upto 89%, 20% in convective heat transfer coefficient and 26% in case of Overall heat transfer coefficient are obtained compared to water.

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Nomenclature

Re	Reynolds number
Nu	Nusselt number
v	Fluid average velocity m/s
h	Convective heat transfer coefficient, W/m^2 K
k	Thermal conductivity, W/m K
Pr	Prandtl number
D_h	Hydraulic diameter, m
T	Temperature, ^oC
b, w	base, water
LMTD	Log Mean Temperature Difference
L	Length of the channel, m
µ	Viscosity