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Experimental Study of CuO/Water Nanofluid Effect on Convective Heat Transfer of a Heat Sink

[1]Mostafa Jalal, [2]Hossein Meisami and [3]Mohammad Pouyagohar

[1]Young Researchers Club, Science and Research Branch,
Islamic Azad University, Tehran, Iran
[2]Sama Technical and Vocational Training College,
Islamic Azad University, Khorasgan Branch, Isfahan, Iran
[3]Department of Mechanical Engineering, Semnan Branch, Islamic Azad University, Semnan, Iran

Abstract: In the present work, improvement of haet transfer of a heat sink by using CuO-water nanofluid has been investigated. Different parameters affecting the heat transfer characteristics were investigated so that the influence of each parameter can be determined. Three volumetric fractions of nanoparticles as $\varphi = 3.5, 4, 4.5$ and 5 vlo% were used to prepare the nanofluid for the experiment. the Reynolds number varied from 400 to 2000, the convective heat transfer coefficients were determined. The results gained in the study showed that dispersion of CuO nanoparticles in water significantly increased the overall heat transfer coefficient while thermal resistance of heat sink decreased. The results also revealed that heat transfer improvement could be achieved by higher vlo% of nanoparticles up to 5 vol%, however, the influence was some what similar for 4.5 and 5 vol%.

Key words: CuO/water nanofluid · Heat transfer · Volumetric fraction · Reynold number

INTRODUCTION

Some devices such as high speed microprocessors, laser applica-tion apparatus, super conducting magnets and opto-electronics re-quire high heat transfer cooling systems. Many techniques have been proposed to enhance the heat transfer in these types of equip-ment. One of the methods is to enhance the thermal characteristics of the heat transfer fluids by adding nanosized solid particles well dispersed in the heat transfer fluids. Since thermal conductivity of most solids is significantly greater than the one of fluids, it is ex-pected that adding nanoparticles to the heat transfer fluids will im-prove significantly their thermal performance. Fluids containing well dispersed and stable suspensions of nanoparticles are referred to as nanofluids [1]. Many investigators have studied the various features of fluid flow and heat transfer behavior of nanofluids over the past 15 years [2-14].

Thermal conductivity of heat transfer fluids is one of the main parameters that have an impact on heat transfer processes. Numerous experimental studies were carried out to determine the effective thermal conductivity of suspensions containing nano-particles (nanofluids). Numerous types of nanoparticles including metallic oxide nanoparticles [15-19], metallic [20-22], nanotubes [23-25] and other types [26] were used in the preparation of nanofluids.

The effect of the thermal conductivity of nanoparticles on the thermal conductivity of nanofluids has also been studied. Two pre-vious works report no significant effect [17, 23] whereas two other works suggest that the effective thermal conductivity of nanofluids increases with an increase in the thermal conductivity of nanoparticles [22, 26]. It is obvious that more investigation must be carried out to elucidate the effect of the characteristics of nanoparticles on the thermal conductivity of nanofluids. The size of nanoparticles is another important factor that affects the thermal conductivity of nanofluids and has been studied by many researchers. Some investigations showed that the enhance-ment in thermal conductivity relative to the base fluid increased with a decrease in the nanoparticles' size [27-29]. The specific surface area of nanoparticles

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Corresponding Author: Mostafa Jalal, Young Researchers Club, Science and Research Branch, Islamic Azad University, Tehran, Iran. Tel: +98 21 73932487.

increases when their size is decreased. Since the heat transfer between particles and the base fluid occurs at particle/fluid interface, it is believed that an increase in the specific surface area of nanoparticles could lead to an in-crease of the effective thermal conductivity of nanofluids.

The enhancement of thermal conductivity observed for nanofluids also depends on the thermal properties of the base fluids, including their thermal conductivity. As expected, for a given con-centration of nanoparticles, results of previous investigations show that the percentage enhancement in the heat transfer coefficient will be greater when the base fluid has a lower thermal conductivity [16, 17, 22]. This trend is in agreement with conventional models such as the Maxwell model. On the other hand, Xie *et al*. [26] have shown that the thermal conductivity enhancement of nanofluids was independent of the base fluid.

Several investigations were carried out to study the effect of tem-perature on the thermal conductivity enhancement of nanofluids. In general, the enhancement in thermal conductivity increases with an increase in temperature. Increasing the temperature increases the mobility of nanoparticles by intensifying the Brownian motion, which in turn increases the thermal conductivity of nanofluids. Changes in temperature may also affect nanoparticle clustering which will in turn affect the thermal conductivity. Beck *et al*. [30, 31] have studied the effect of temperature on the thermal conductivity of nanofluids and showed that there exists an optimum temperature at which thermal conductivity of nanofluids is maximum. On the other hand, other investigations indicate that the enhancement of the nanofluid thermal conductivity is independent of temperature.

Preparation and Properties of Nanofluids: The copper dioxide (CuO) nanoparticles (purchased from Yong-Zhen Technomaterial Co. Ltd.) with an averaged particle size of 20±5 nm and 99.9% purity were dispersed in distilled water, as the base fluid, to form the CuO -water nanofluids. X-ray difraction (XRD) pattern and SEM micrograph of the CuO nanoparticles are presented in Fig. 1 and 2 respectively. TEM image of the nanoparticles in water is also shown in Fig. 3.

The nanofluids were synthesized by the two-step method, without any surfactant in order to not affect the viscosity and the thermal conductivity of suspensions. Desired volume fraction of CuO-water nanofluids were prepared by mixing appropriate quantities of nanoparticles with the base fluid and then sonicated by an ultrasonic bath (Hielscher UP400S, H40 sonotrode) for at least 90 min. The CuO nanofluids used in the current study stayed stable for a period of 72 h without any visible settlement. Four volumetric fractions of the CuO -water nanofluid, φ = 3.5, 4, 4.5 and 5 vol.%, were prepared for the experiment.

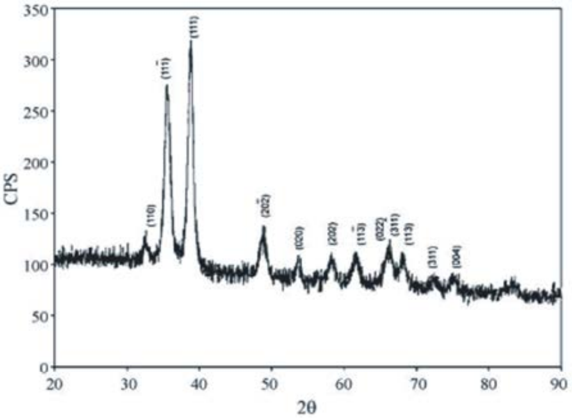

Fig. 1: X-ray diffraction pattern of CuO nanoparticles

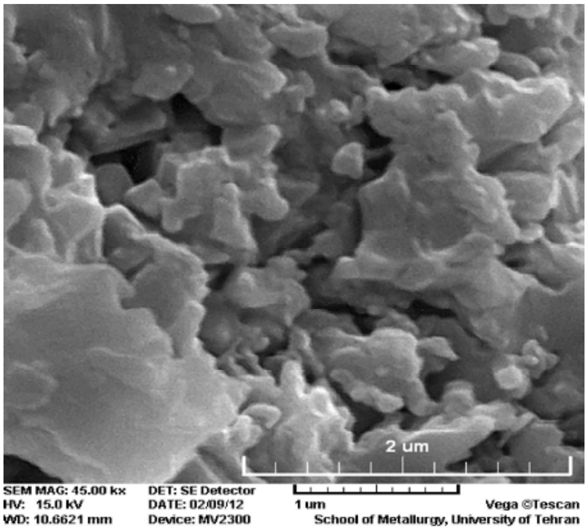

Fig. 2: SEM images of CuO nanoparticles

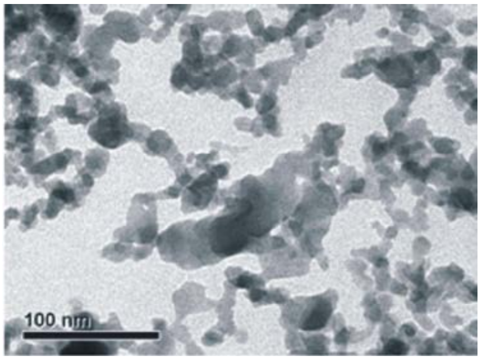

Fig. 3: TEM images of CuO nanoparticles in water

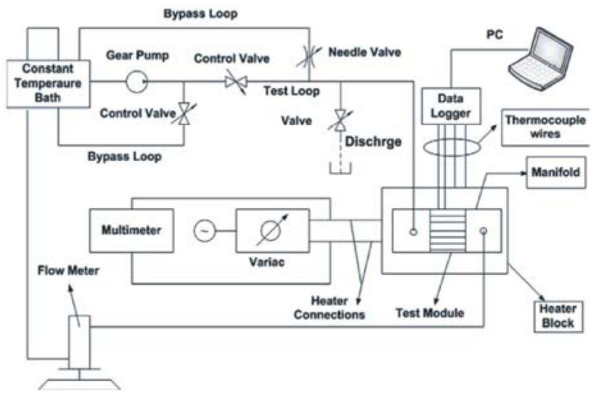

Fig. 4: Schematic of the experimental setup

Experimental Apparatus: Fig. 4 demonstrates the flow loop and components that was designed and constructed for the present study.

The main components of the test apparatus are: a closed-loop for circulating the fluid, heat sink test section and data acquisition system. Fluid is sent into the loop from a holding tank and is continuously circulated by a gear pump which can be operated at variable rotation speeds to supply different flow rates. A constant temperature bath (F10-Hc Julabo) was installed upstream of the gear pump to control the heat sink inlet temperature. The loop flow rate is controlled upon exiting the pump by two by-pass lines and using three ball valves for coarse adjustment and a needle valve which allows fine adjustment of the flow rate. Volumetric flow rate passing through the loop was measured using a calibrated flow meter.

The test module consists mainly of a miniature channel heat sink, housing, plexiglass cover plates as insulation and the heater. The miniature channel heat sink was fabricated from a square block of aluminum with dimensions 40 mm □ 40 mm □ 10 mm using a wire-cut machine. The channels have circular shape with an internal diameter of 4 mm.

The heat sink assembly was placed inside a plexiglass shroud isolated from the ambient. Because of plexiglass low thermal conductivity, the effect of lateral heat transfer from the sides of the test section is eliminated. All the thermocouples used in this study were calibrated and the uncertainty of the temperature measurement was estimated to be less than 5%. Two K-type thermocouples, coated with a compound of copper powder and thermal paste, were embedded in the heat sink for measuring the base plate temperature. Also located in the inlet and outlet of manifold were two K-type thermocouples inserted to measure the inlet and exit temperatures of the fluid.

Table 1: Uncertainty of measurements

Quality	Uncertainty
Heat flux (W/m^2)	±5.3%
Temperature (°C)	±0.1%
Heat transfer coefficient (W/m^{2}K)	±4.2%

In order to provide a constant heat flux surface for simulating an electronic chip, a heater block, was fabricated from the same material used in constructing the heat sink.

Six holes were drilled in the upper cylindrical part of the heater block for embedding K-type thermocouples, three of which have a depth of 3cm and the other three have a depth of 1.5 cm. These thermocouples will later be used for extrapolating of heat sink base plate temperature. Isolation of heater block from surrounding is done by placing it in a thick fiberboard box filled with slag wool, so that heat transfer interaction could only take place at the interface of the heater block and the heat sink.

To improve the thermal transfer efficiency, a layer of highly thermally conductive thermal grease was located at the contact surface between heat sink and heater block. The set of thermocouples were connected to a Testo 177-T4 data logger through an eight channel selector and all the temperatures required for the analysis of heat sink and heater were recorded simultaneously into the computer by means of a USB port. Uncertainty of the experimental data may origin from the measuring errors of quantities such as heat flux or temperature. The uncertainties of the measurements in the present study are reported in Table 1.

Experimental Results and Discussion: The particle volume fraction of the nanofluid used in this study was in the range of 3-5%. Flow rate and inlet temperature for both pure water and nanofluids were the same. Flow rates chosen for this study were 4.46, 12.28, 21.76 and 25.8 cc/s. Inlet temperature was fixed at 27°C. The comparison between the performances of water and CuO-nanofluids as coolants is demonstrated as below.

Fig. 5 depicts the effect of nanoparticles concentration on temperature difference between two ends of heat sink base plate when flow rate was adjusted to 4.46 cc/s. It was found that there is a linear relation between heat transfer enhancement and volume fraction of particles.

Fig. 6 shows the convective heat transfer coefficient as a function of Reynolds number of the pure water and the CuO-water nanofluids at different particle volume factions in laminar flow. As the Reynolds number varied

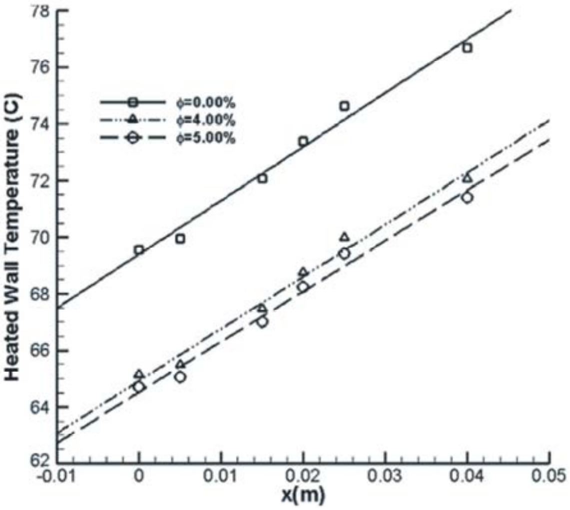

Fig. 5: Base plate temperature variation

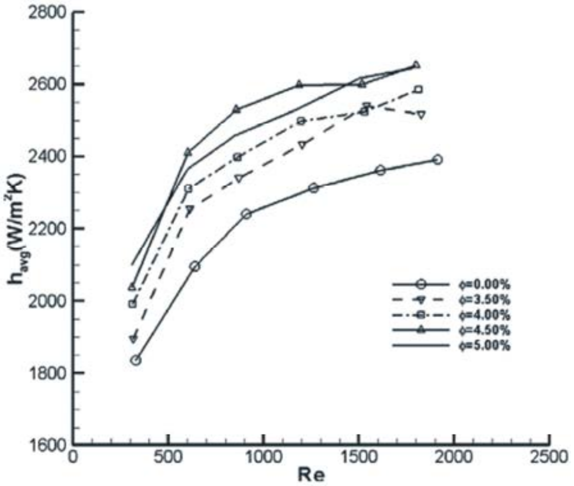

Fig. 6: Heat transfer coefficient enhancement of using CuO -water nanofluid

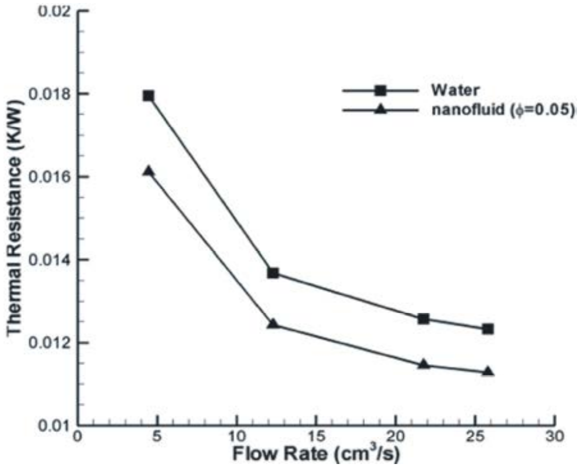

Fig. 7: Thermal resistance as a function of flow rate

from 400 to 2000, the heat transfer coefficients of the nanofluids with the volume fractions of 3.5%, 4%, 4.5% and 5% increased by 3-8%, 8-8.5%, 10.5-13% and 9-15% as compared with that of pure water, respectively. Also, at different Reynolds numbers with an increase in the volume flow rate, the heat transfer coefficient didn't follow a constant behavior. At some Reynolds numbers, an increase of the volume flow rate resulted in the elevation of heat transfer enhancement and in other Reynolds numbers a declination was observed. Another result which can be derived from Fig. 6 is that higher particle concentration leads to more heat transfer enhancement. While heat transfer enhancement when using nanoparticles depends on flow conditions (such as Reynolds number), it can be attributed to different issues, such as Brownian motion, high thermal conductivity of nanofluid suspensions due to the role of interfacial layers, near wall particles interaction effects, reduction of boundary layer thickness and delay in boundary layer development [32, 33].

The cooling performance of a heat sink with nanofluids can be stated as the thermal resistance defined as:

$$\theta = \frac{(T_{max} - T_{in})}{q''} \qquad (1)$$

where *q"*, *Tin* and *Tmax* are heat flux, inlet coolant temperature and the maximum temperature of the heat sink base plate, respectively. In our study the base plate temperatures measured near the outlet of flow were treated as the maximum temperatures. The thermal resistances of pure water and 5% volume fraction nanofluid for a 180 W/cm2 heat flux input and different flow rates are illustrated in Fig. 7.

It shows that in the investigated range of flow rates the thermal resistance defined by Eq. (1) is reduced when nanofluid is applied as coolant. This enhancement in heat transfer of heat sinks indi-cates that nanofluids could be a promising replacement for pure water in systems where there is need to more efficient heat transfer.

CONCLUSION

In this study, heat transfer characteristics of a mini-channel heat sink cooled by CuO-water nanofluid were investigated both experimentally and numerically. Tests were performed for volume fractions in the range of 3.5-5%. The obtained temperature distributions are then used to evaluate the thermal resistance that characterizes the heat sink performance. Key findings from the study are as follows:

- CuO nanoparticles dispersed into the water increased heat transfer coefficient of the heat sink significantly. This outperformance can be mainly attributed to higher thermal conductivity of the nanofluids and Brownian motion of particles.
- Amount of augmentation in heat transfer coefficient increased with increasing particle concentrations and the amount of heat transfer enhancement did not decrease at higher Reynolds numbers.
- Thermal resistance of the miniature heat sink was decreased to as low as 0.325 K/W and by about 10% due to the decreased temperature of base plate when using CuO -water nanofluids.

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