Nanofluid laminar convection heat transfer

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Abstract

Convective heat transfer of $CuO/water$ nanofluid which is a suspension of CuO nanoparticles added to water through circular tube was investigated experimentally. Flow was laminar and constant wall temperature was used as thermal boundary condition. It is found that heat transfer coefficients increase by nanoparticles concentration as well as Peclet number. Measured heat transfer coefficients were greater than the values predicted by single phase heat transfer correlation with nanofluids physical and thermal properties. Also experimental results show Newtonian behavior for $CuO/water$ nanofluid at concentration up to 3.0% volume fraction.

1. Introduction

Nanofluids include suspension of metallic or nonmetallic nanopowders in base liquid and can be employed to increase heat transfer rate in various applications [1]. Considering very small particle size and their small volume fraction, problems such as clogging and pressure drop increase become insignificant for nanofluids. Nanofluids found to possess long time stability and large efficient thermal conductivity. Das et al. [2] investigated the temperature dependence of thermal conductivity enhancement in nanofluids experimentally. Two to four fold increases in thermal conductivity of nanofluid was observed over a temperature range of $21°C$ to $51°C$. Since the theoretical models such as Hamilton-Crosser model [3] can not predict thermal conductivity of nanofluids accurately, it is necessary to study thermal conductivity enhancement mechanisms of this kind of fluids.

There are only few previous studies involve in describing fluid flow and convective heat transfer performance of nanofluids. For example Xuan and Li [4] measured the convective heat transfer coefficient and friction factor of $Cu/water$ nanofluids in turbulent flow. Their results show that the heat transfer coefficient of a nanofluid containing 2.0% volume of Cu nanoparticles improves more than 39% compared with pure water. Nanofluid phase change

was investigated by Das et al. [5]. They observed boiling performance deterioration for nanofluids.

The aim of the present study is to investigate convective heat transfer of CuO / $water$ nanofluid under constant wall temperature and different concentrations of nanoparticles in laminar flow regime.

2. Experiments

In this study CuO / $water$ nanofluid was used in which CuO Nanoparticle with an average diameter of $50 - 60$ nm was dispersed in water. The nanofluids with seven different CuO nanoparticle concentrations ($0.2\% - 3.0\%$ volume fraction) were prepared and used to study enhancement of heat transfer.

The rheological properties of sample nanofluids were measured using cylindrical rheometer (Model HAAK RV12) at $24^{\circ}C$. As shown in Fig. (1) the shear stress versus shear rate curves are almost linear and similar to what obtained for water under the same conditions and confirm a Newtonian behavior for CuO / $water$ nanofluid in concentration up to 3.0% volume fraction.
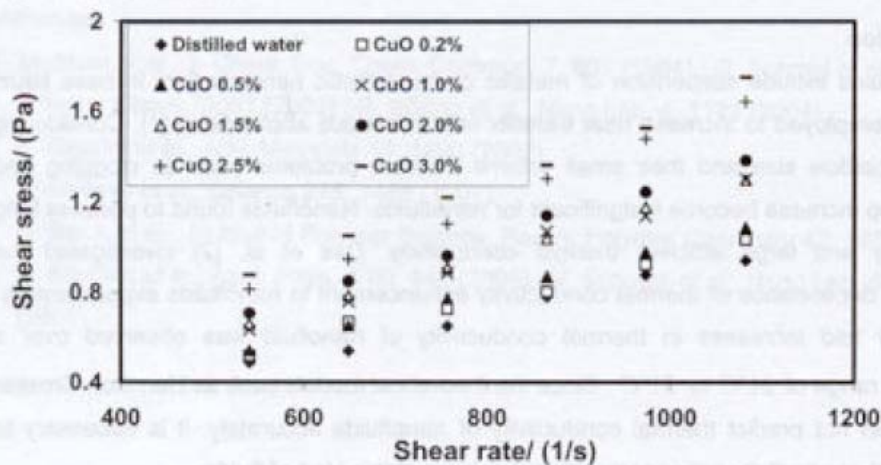

Fig. 1:   Shear stress versus shear rate for different CuO / $water$ nanofluid concentrations

Test section consisted of experimental setup 1 m annular tube which was constructed of 6 mm diameter inner copper tube with 0.5 mm thickness and 32 mm diameter outer stainless steel tube. Nanofluid flows inside the inner tube while saturated steam entered annular section, which created constant wall temperature boundary condition. Figure (2)

presents Nusselt number variations versus Peclet number for different volume fractions of nanoparticles. Based on this Figure the Nusselt number for nanofluid is greater than for water and the heat transfer enhancement is higher for higher concentrations of particles.
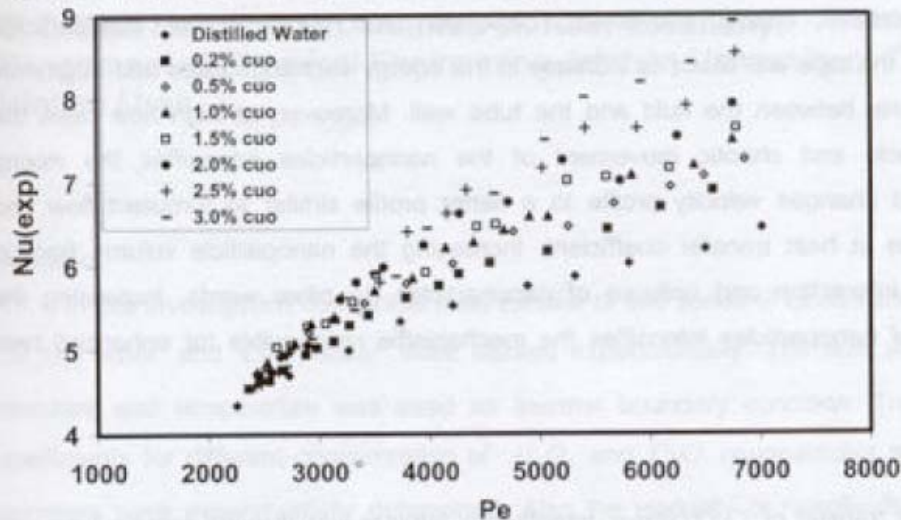
Fig. 2: Experimental Nusselt number for water and $CuO/water$ nanofluid versus Peclet number at different concentration
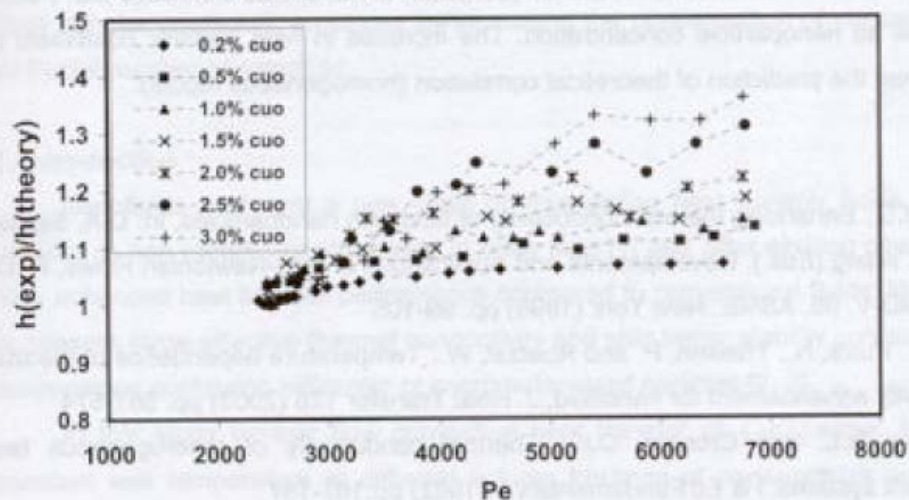
Fig. 3: $CuO/water$ nanofluids experimental heat transfer coefficient ratio to Seider-Tate equation results versus Peclet Number

Figure (3) shows the ratio of the experimental heat transfer coefficients to the results obtained from homogeneous model (Seider–Tate equation [6]). This ratio increases with Peclet number as well as nanoparticle concentration. For example at Peclet number 6000 as the $CuO/water$ nanofluid concentration changes from 0.2% to 2.5% the ratio increases

from 1.07 to 1.25. Also at 2.5% volume fraction CuO nanoparticles the ratio increases from 1.01 to 1.31 by changing Peclet number from 2500 to 6700.

Addition of nanoparticles to fluid changes the flow structure so that besides thermal conductivity increase, chaotic movement, dispersion and fluctuation of nanoparticles especially near the tube wall leads to increase in the energy exchange rates and augments heat transfer rate between the fluid and the tube wall. Moreover, at high flow rates the dispersion effects and chaotic movement of the nanoparticles intensifies the mixing fluctuations and changes velocity profile to a flatter profile similar to turbulent flow and causes increase in heat transfer coefficient. Increasing the nanoparticle volume fraction intensifies the interaction and collision of nanoparticles. In other words, increasing the concentration of nanoparticles intensifies the mechanisms responsible for enhanced heat transfer.

Conclusion

Convective heat transfer of $CuO/water$ nanofluid in laminar flow through circular tube with constant wall temperature boundary condition was investigated experimentally. The experimental results indicate that heat transfer coefficient of nanofluids increases with Peclet number as well as nanoparticle concentration. The increase in heat transfer coefficient is much higher than the prediction of theoretical correlation (homogeneous model).

Reference

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