HEAT TRANSFER ENHANCEMENT OF NANOFLUID LAMINAR FLOW

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Abstract
Nanofluids refer to a new kind of heat transfer fluids with suspended nanoparticles and can be employed to increase heat transfer rate in various applications. In this investigation laminar convective heat transfer of three series of metallic and non-metallic nanofluids through circular tube under constant wall temperature boundary condition investigated experimentally. The heat transfer coefficients for different concentration of Al_2O_3, CuO and Cu nanoparticles at various Peclet numbers were determined. The experimental results emphasize on the enhancement of heat transfer by increasing the concentration of nanoparticles as well as Peclet number for each nanofluid but measured results are greater than the values predicted by theoretical correlations.

Keywords: Nanofluid – nanoparticle – laminar flow – Heat Transfer Enhancement

Introduction
Traditional heat transfer fluids such as water, ethylene glycol and oil have inherently low thermal conductivity relative to metals and even metal oxides. Therefore, fluids with suspended solid particles are expected to have better heat transfer properties compared to conventional heat transfer fluids [1]. Practical application of these coolants with suspended particles of the magnitude millimeter or micrometer sized in them shows some problems such as instability of particles, erosion and flow channel clogging and extra pressure drop in flow channel. New advances in producing nano-sized metallic or nonmetallic particles have allowed producing new kind of fluid named as nanofluid. Probably Choi [2] at the Argonne national laboratory was the first to employ the particles of nanometer dimension suspended in solution as nanofluid and showed considerable increase in the nanofluid thermal conductivity. Nanofluids due to their excellent properties including better stability and increased thermal conductivity have been investigated by several researchers [3-5]. For example Eastman [6] reported that the $Cu/ethylene\ glycol$ nanofluid with 0.3% volume of Cu nanoparticles can enhance thermal conductivity up to 40%. There are only few previous studies involve in describing fluid flow and convective heat transfer performance of the nanofluids [7-10]. Lee and Choi [11] studied convective heat transfer of laminar flow of an unspecified nanofluid in micro channels, and observed a reduction in thermal resistance by a factor 2. Putra [12] reported suppression of natural convection heat transfer by nanofluid of $Al_2O_3/water$ and $CuO/water$ and concluded that this could be due to several factors such as nanoparticle settling and velocity difference between nanoparticles and main fluid. Nanofluid heat transfer during boiling process was investigated experimentally by Das et al. [13] and observed boiling performance deterioration for nanofluids containing nanoparticles.

The object of this study is to investigate laminar flow convective heat transfer and rheological properties of $Al_2O_3/water$, $CuO/water$ and $Cu/water$ nanofluids under constant wall temperature boundary condition and different concentration of nanoparticles.

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Experiments

The process used to disperse nanoparticles in liquid plays a critical role in nanofluid properties. In this study water based nanofluids of different oxide and metal nanoparticles including Al_2O_3, CuO and Cu with 20 nm, 50-60 nm and 25 nm diameters respectively in different volume concentrations ($0.2\% - 3.0\%$) were employed to study enhancement of convective heat transfer in circular tube with constant wall temperature. After weighting the required powder, nanoparticles were mixed with distilled water in a flask and then vibrated for 8-16 hour in ultrasonic mixer system (model Parsonic 3600 S). No sedimentation was observed for any concentration of nanofluid suspension after 24 hours.

The dynamic viscosity of nanofluids was measured using cylindrical rheometer (Model HAAK RV12) at $24^{\circ}C$ and compared with theoretical correlation (Einstein model [14]) as follow:

$$\mu_{nf} = \mu_w.(1 + 2.5\nu) \tag{1}$$

In above equation μ_{nf} is nanofluid viscosity, μ_w is water viscosity and ν is volume concentration of nanoparticles.

As shown in Figure (1) the values of viscosities versus shear rate are almost constant and confirm a Newtonian behavior for Al_2O_3, CuO and Cu in volume fraction up to 3.0% of nanoparticles. According to Figure (1) $CuO/water$ nanofluid have higher viscosity in comparison with $Al_2O_3/water$ and $Cu/water$ nanofluids at constant concentration conditions. This may result from the large particle size of CuO nanoparticles.

In order to study convective heat transfer under constant wall temperature boundary condition an experimental setup was designed and constructed. The test section constructed of 1 m annular tube which was constructed of 6 mm diameter inner copper tube with 0.5mm 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. The experiments were conducted in laminar flow over a range of Reynolds number 600<Re<2000.

Figure (2) shows experimental heat transfer coefficient of nanofluids versus Peclet number at different concentrations. The experimental results show that the heat transfer coefficient of nanofluids increases by nanoparticle volume fraction as well as Peclet number. Regarding the experimental results there is low heat transfer enhancement for $CuO/water$ nanofluid compared with $Al_2O_3/water$ and $Cu/water$ nanofluids.

The Seider- Tate equation [15] for convective heat transfer of laminar flow in tube was used to compare with experimental results:

$$\overline{Nu_{nf}}(th) = 1.86(\mathrm{Re}_{nf}\,.\,\mathrm{Pr}_{nf}\,.\,\frac{D}{L})^{1/3}(\frac{\mu_{nf}}{\mu_{Wnf}})^{0.14} \tag{2}$$

In which D is tube diameter (m), L is tube length (m), μ_{nf} is nanofluid viscosity, μ_{wnf} is nanofluid viscosity at wall temperature, $\overline{Nu_{nf}}(th)$ is Nusselt number of nanofluid, Re_{nf} and Pr_{nf} are Reynolds number and Prandtl number of nanofluid respectively

In order to evaluate quantitatively the experimental heat transfer enhancement in comparison with Seider–Tate equation prediction, the ratio of experimental Nusselt number to that of theoretical values for each nanofluid determined and presented in Figure (3) against Peclet number. The results clearly show the enhancement of heat transfer coefficient for both nanofluids with nanoparticles concentrations as well as Peclet number, and the $Cu/water$ nanofluid shows more enhancement in comparison with $Al_2O_3/water$ and $CuO/water$ nanofluids especially at high nanoparticles concentrations.

Experimental results emphasize to existing an optimum concentration for all types of nanofluids in which better enhancement for heat transfer is available. It is due to the fact that as the nanoparticles concentration increases, the viscosity of nanofluids sharply intensifies and the heat transfer enhancement by nanofluids reduces in higher nanoparticles concentrations. It is found that the optimum concentrations for $Al_2O_3/water$ and $CuO/water$ nanofluids are between $2.5\% - 3.0\%$ and for $Cu/water$ is between $2.0\% - 2.5\%$ by volume.

The experimental results indicate that the single phase correlation is not able to predict heat transfer enhancement by nanofluid. Therefore, increased thermal conductivity is not the only mechanism responsible for heat transfer enhancement. 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

This paper presents the experimental result of the convective heat transfer of $Al_2O_3/water$, $CuO/water$ and $Cu/water$ nanofluids. The flow was laminar and constant wall temperature was considered as thermal boundary condition. The experimental results represent that the Heat transfer coefficients of all nanofluids are enhanced with Peclet number as well as nanoparticle concentrations. The heat transfer coefficient enhancements for all nanofluids are higher than the prediction of single phase heat transfer correlation with nanofluids properties. Nanofluid contain metal nanoparticle ($Cu/water$) show more enhancement compared to oxide nanofluids ($Al_2O_3/water$ and $CuO/water$). Also $CuO/water$ nanofluid present less enhancement in heat transfer coefficient at the same Peclet number and nanoparticles concentration. It is related to large particle size and high viscosity of $CuO/water$ and high thermal conductivity of $Cu/water$ nanofluid. There is an optimum concentration for each nanofluid in which more enhancements available.

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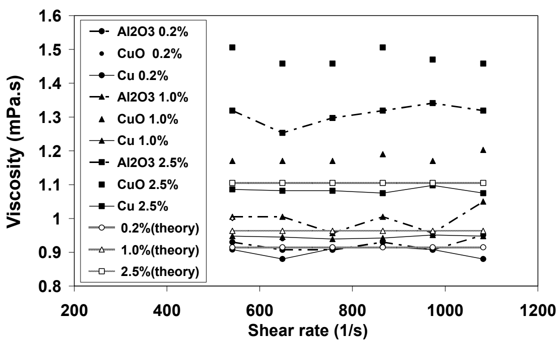

Fig. 1-Experimental and theoretical viscosity versus shear rate for $Al_2O_3/water$, $CuO/water$ and $Cu/water$ nanofluids at different concentration

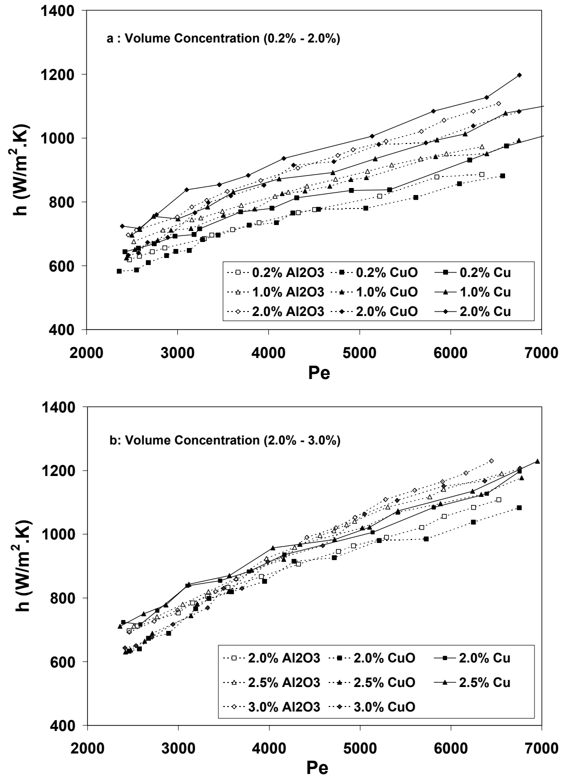

Fig. 2- Experimental heat transfer coefficient versus Peclet number for $Al_2O_3 / water$, $CuO / water$ and $Cu / water$ nanofluids at different concentration (a) volume concentration between $0.2\% - 2.0\%$ (b) volume concentration between $2.0\% - 3.0\%$

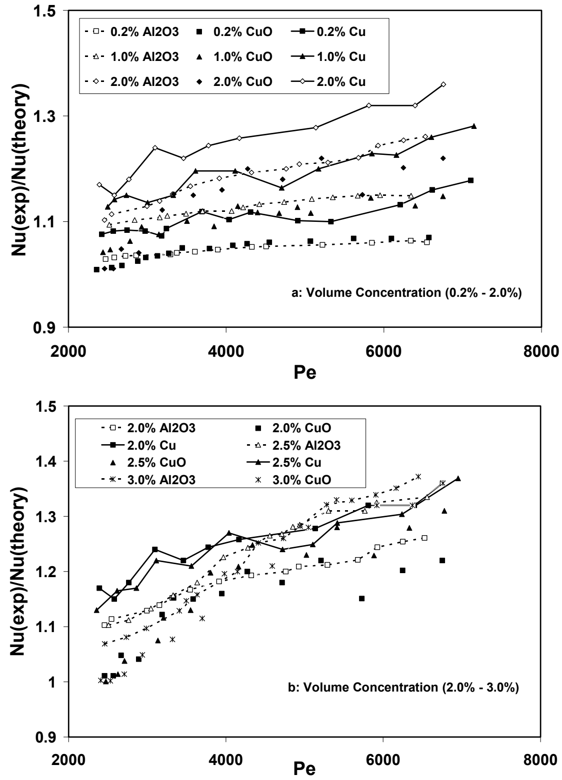

Fig. 3. The experimental Nusselt number ratio to Seider-Tate equation result for $Al_2O_3 / water$, $CuO / water$ and $Cu / water$ nanofluids at different concentration (a) volume concentrations between $0.2\% - 2.0\%$ (b) volume concentrations between $2.0\% - 3.0\%$