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Research Paper

Combined free and forced convection heat transfer of the copper oxide-heat transfer oil (CuO-HTO) nanofluid inside horizontal tubes under constant wall temperature

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HIGHLIGHTS

- CuO nanoparticles may enhance Nusselt number of HTO mixed flow up to 44%.
- The classic correlations cannot be used to evaluate HTO-CuO nanofluid mixed flow.
- Jakson correlation is able to estimate HTO-CuO mixed flow Nusselt number in horizontal tubes.
- The classic correlations are not proper to predict Nusselt number of HTO-CuO mixed flow in horizontal tubes.
- The performance index of HTO-CuO mixed flow in horizontal tubes is more than unity.

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ABSTRACT

In this paper, the combined free and forced convection heat transfer of the heat transfer oil-copper oxide (HTO-CuO) nanofluid flow in horizontal tubes is studied experimentally. The flow regime is laminar and the surface temperature is constant. The effect of nanoparticle mass concentration and microfin tube on the heat transfer rate is investigated as Richardson number is between 0.1 and 0.7. The results show that the combined free and forced convection heat transfer rate increase significantly with the increase in nanoparticle concentration from 0% to 1.5%. As shown in the results, three new correlations are presented to predict the mixed heat transfer rate based on increasing the Richardson number from 0.04 to 0.7. The maximum deviation of both correlations is less than 10%. In addition, a new correlation is suggested to assess the Nusselt number based on the Rayleigh number in horizontal tubes from 1656000 to 8200000. The maximum deviation of the correlation is almost 5%.

1. Introduction

Mixed convection heat transfer is widely used in industrial applications, e.g. advanced technologies such as microelectronics cooling, air conditioning, as well as petrochemical, oil and gas industries. Enhancement of the mixed convection heat transfer has a significant role on the energy saving and on the compactness perspectives of the heat exchangers. Depew and August [1] performed an experiment on combined free and forced convection and pressure drop of fluid, which had laminar regime in horizontal tubes. In these researches, two new correlations have been presented to evaluate the mixed convection in these works. They proposed that the maximum error of correlations is 40%. Hieber [2] carried out numerically study on mixed convection in isothermally horizontal pipe to introduce the theoretical equation. Reporting the deviation of correlations is less than 15%. Rustum and Soliman [3] made an experimental analysis of laminar mixed convection in a horizontal internally finned tube. They mentioned that the geometrical parameters have substantial impact on secondary flow current, which is in turn reflected on the axial velocity, temperature distributions, friction factor, and Nusselt number. Moreover, the correlation was suggested using empirical data to predict the mixed convection. Owing to the deviation from 10% to 17%, the result is eligible to evaluate the combined free and forced convection in internally horizontal finned tubes.

Besides, low convective heat transfer rate is the low thermal conductivity of conventional fluids such as water, ethylene glycol, oil and so on. Owing to weak thermal conductivity of conventional fluids, researchers used contemporary technology to enhance the heat mixed heat transfer rate, which is applied to reduce the heat exchanger size and energy consumption. Hence, several scientists used nanoparticle to improve the forced convection and mixed

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convection heat transfer rate in heat exchangers [4]. Ali et al [5] carried out an experiment on convection heat transfer augmentation for car radiator using ZnO-water nanofluid. The best heat transfer enhancement up to 46% was found compared to base fluid at 0.2% volumetric concentration. Ghazvini et al. [6] carried out an experimental investigation on the heat transfer and the pressure drop of nanodiamond-engine oil nanofluid flow in a microfin tube under the uniform heat flux condition. They observed that the heat transfer rate of the nanofluid flow increased 55%. Recently, Akhavan et al. [7] performed an experimental investigation on the heat transfer and the pressure drop of heat transfer oil-copper oxide nanofluid flow in smooth and micro-fin tubes. The results showed that the heat transfer coefficient and the pressure drop may increase up to 57% and 47%, respectively. Wen and Ding [8] performed an experimental investigation on natural convective heat transfer in horizontal tube. They found the natural convective heat transfer coefficient decreases by using nanofluid. Akbarinia et al. [9], and Mirmasoumi and Behzadmehr [10] studied numerically the fully developed laminar mixed convection heat transfer of water-Al_2O_3 nanofluid in horizontal tubes. The results showed that although the nanoparticles concentration has no significant influence on the hydrodynamics of the flow, it enhances the heat transfer coefficient. However, the heat transfer coefficient reached the peak at 10%. Ben Mansour et al. [11] investigated numerically the same problem. Their results showed that the natural convection is enhanced as the Grashof number increases. Accordingly, the Grashof number increase when kinematic viscosity decreases what it has obtained in experimental research. The results showed that the average Nusselt number is increased with both Reynolds and Grashof numbers. The major reason for the heat transfer enhancement is the increment of the viscosity and Prandtl number. New correlations were also fitted the data within ±10% accuracy. Feng et al. [12] studied the hydrodynamic and thermal performance of nanofluids in the thermally developing region of the laminar mixed flow. They proposed a new correlation to predict the effect of the Rayleigh number based on Gratz number.

Golla et al. [13] conducted an experimental laminar mixed convection of TiO_2-water nanofluid in horizontal uniformly heated pipe flow. They reported the adding nanoparticle to water have no effect on mixed convection. Recently, Derakhshan et al. [14–19] conducted an experiment on the mixed convection heat transfer characteristic of MWCNT (multi walled carbon nanotube) heat transfer oil based nanofluid inside smooth and microfin tubes. The performance index of the tested microfin and smooth tubes have been assessed in this work, which illustrates that the heat transfer rate is enhanced more than the pressure drop using this technique. The results demonstrated that the heat transfer may be increased up to 4% and 8% in smooth and microfine tube, respectively.

In this work, the influence of using copper oxide nanoparticle to the pure heat transfer oil flow on the combined free and forced heat transfer in horizontal tubes has been performed experimentally. The tube surface temperature in constant and the flow rate is low enough to ensure that the flow regime stays laminar. Due to the lack of the mixed convection correlation in microfin tube under constant wall temperature and laminar flow, two correlation for the mixed convection in microfin tube are presented.

2. An experimental program

2.1. Nanofluid properties

In this study, solid particles of copper oxide with the average size of 40 nm and the purity of 99% were used as nanoparticles. SEM (scanning electron microscope) image of the nanoparticles is indicated in Fig. 1.

As shown in the figure, the nanoparticles are of irregular shapes. In order to obtain a homogeneous and a relatively stable nanofluid, an ultrasonic UPS400 apparatus with a frequency of 24 kHz and

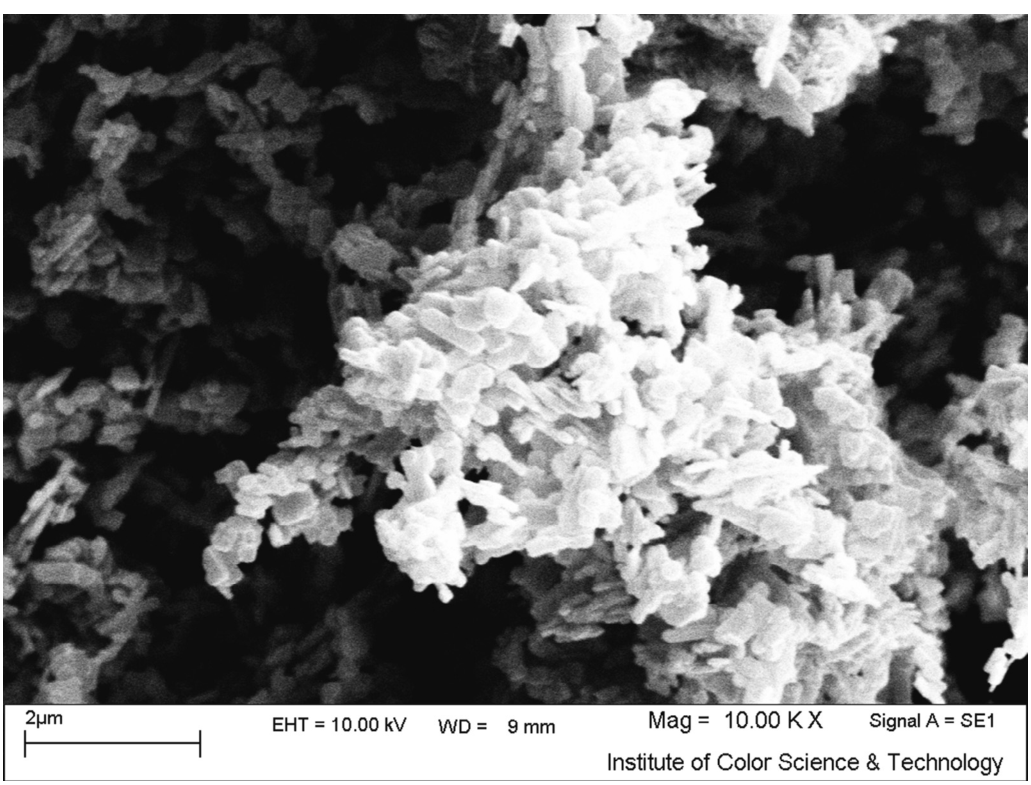

Fig. 1. SEM image of the copper oxide nanoparticles.