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An empirical study on heat transfer and pressure drop properties of heat transfer oil-copper oxide nanofluid in microfin tubes☆

M.A. Akhavan-Behabadi [a],*, F. Hekmatipour [b], S.M. Mirhabibi [b], B. Sajadi [a]

[a] Center of Excellence in Design and Optimization of Energy Systems, School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran
[b] Department of Energy and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran

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ABSTRACT

In this paper, the convective heat transfer of the heat transfer oil-copper oxide nanofluid flow in horizontal smooth and microfin tubes is investigated experimentally. Using a flow control system, the flow regime is always laminar and the wall temperature is constant by using a steam tank. Pure heat transfer oil and nanofluid with the weight concentrations of 0.5%, 1% and 1.5% are used as working fluids. The results are in good agreement with the classic correlations for the pure fluid flow. Based on the results, combination use of nanoparticles and the microfin tube leads to the heat transfer enhancement up to 230%, in comparison with the base fluid flow in the smooth tube. The results are useful in the prediction of the heat transfer rate and the pressure drop in nanofluid flows.

1. Introduction

Nowadays, the heat transfer has an important role in advanced technologies such as: mechatronics, microelectronics, power generation, air conditioning, and petrochemical, oil and gas industries. One of the reasons for low convective heat transfer rate is the low thermal conductivity of conventional fluids such as water, ethylene glycol, oil and so on. Weak thermal conductivity of conventional fluids causes a fundamental restriction in the heat transfer rate. As technology progresses, manufacturing of various metal and non-metal nanoparticles becomes possible. Thermal conductivity of nanoparticles is higher than conventional fluids which makes them proper choices to produce nanofluids. A nanofluid is made by adding metal or non-metal nanoparticles to a base fluid. Due to thermo-physical properties of nanoparticles, it is expected that nanofluids have higher thermal conductivity than the base fluid. In the recent years, many studies have been conducted to investigate the nanofluid properties.

First time, Eastman et al. [1] conducted experiments on nanofluids using CuO particles in the water base fluid. Li et al. [2] (have) studied four nanofluids including water-aluminum oxide, water-copper oxide, ethylene glycol-aluminum oxide and ethylene glycol-copper oxide. The results showed that the thermal conductivity of nanofluids increases compared to the base fluid. In addition, the measured conductivity is more than the values predicted by macroscopic models.

Zhu et al. [3] applied chemical methods to stabilize copper oxide nanofluids. They observed that the concentration of copper salt and the reaction time depend on the size and the cluster shape of primary nanoparticles. In addition, the thermal conductivity of the copper oxide nanofluid is 1 to 5% more than the base fluid.

Sphaier et al. [4] conducted experiments on the thermal conductivity of polyester-aluminum oxide and polyester-copper oxide nanofluids and observed that using nanoparticles enhances the thermal conductivity of the base fluid.

Zeinali Heris et al. [5] studied experimentally the convective heat transfer of water-aluminum oxide nanofluid flow in a horizontal smooth tube with uniform wall temperature as the flow regime is laminar. They reported that the convective heat transfer of the nanofluid in the mass concentration of 2.5% volume fraction and Peclet number of 6000 may increase up to 40%. They also mentioned that the possible reasons of this increment, especially at the high Peclet number, are motion, relocation and collision of the nanoparticles which change the flow structure and enhance the heat transfer rate to the bulk fluid.

Akhavan 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%. In other research works, Akhavan et al. [7,8] examined the rheological and the thermal characteristics of the base oil-copper oxide nanofluid in the round tubes. They also conducted an experimental study on the pressure drop and the heat transfer of nanofluid flow in tubes using internal wired coils under the constant heat flux condition. Based on their results, the maximum increment in the heat transfer coefficient and the pressure drops were 45% and 65%, respectively.

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* Corresponding author.
E-mail address: akhavan@ut.ac.ir (M.A. Akhavan-Behabadi).

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Nomenclature

Cp	specific heat capacity (kJ/kg · K)
D	tube diameter (m)
D_h	hydraulic tube diameter (m)
F	Darcy's friction factor
$\overline{h}$	average convective heat transfer coefficient ($\mathrm{W/m^2 \cdot K}$)
L	tube length (m)
K	thermal conductivity (W/m · K)
N	number of fins
Greek symbols	
θ	vortex angle (°)
ρ	density ($\mathrm{kg/m^3}$)
μ	dynamic viscosity (pa · s)
ϕ	nanoparticle weight concentration (%)
φ	nanoparticle volumetric concentration (%)
γ	helix angle (°)
Subscripts	
b	bulk fluid
f	base fluid
i	inlet
n_f	nanofluid
o	outlet
w	wall

Akhavan and Hashemi [9] investigated experimentally the pressure drop and the heat transfer characteristics of the base oil-copper oxide nanofluid in a horizontal helical coil as the heat flux was constant. They reported that the heat transfer coefficient enhancement may be up to 30.4% which leads to 18% increment in the pressure drop.

Akhavan et al. [10] conducted an experimental research work on the heat transfer rate of the heat transfer oil-carbon nanotube nanofluid flow in flat tubes under the constant wall temperature condition. They observed that the Nusselt number of the flow significantly increases due to using nanoparticles.

Akhavan et al. [11–13] studied experimentally the thermo-physical properties and the convection heat transfer of the heat transfer oil-carbon nanotube nanofluid flow inside vertical helical coils as the wall temperature was constant. They found that the convection heat transfer in the nanofluid flow with a mass concentration of 0.4%, equals to 60%.

In this research, the effect of using copper oxide nanoparticles on the heat transfer rate and the pressure drop of the heat transfer oil flow in simple and microfin tubes has been studied experimentally as the flow regime is laminar and the wall temperature is constant. The results may be used in deigning heat exchangers and in improving the prediction of the heat transfer rate and the pressure drop in nanofluid flows.

2. 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) Nanograph image of the nanoparticles is presented in Fig. 1.

As shown in the figure, the nanoparticles are almost spherical. In order to obtain a homogeneous and a relatively stable nanofluid, an ultrasonic UPS400 apparatus with the frequency of 24 kHz and the power of 400 W was used. In this study, three samples of nanofluids were prepared including suspension of heat transfer oil-copper oxide nanoparticles with the mass concentration of 0.5%, 1% and 1.5%. The nanofluids were stable for 48 h, After 48 h, the nanoparticles started to precipitate and settled down completely for 7 days.

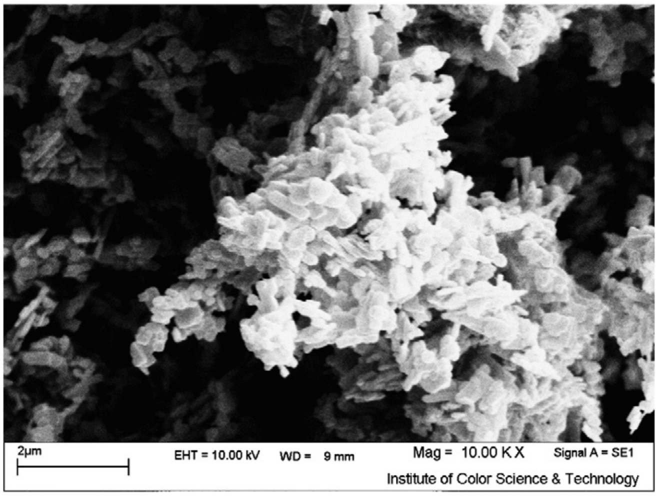

Fig. 1. SEM image of the copper oxide nanoparticles.

2.2. Test setup

In order to investigate the convective heat transfer and the pressure drop in tubes under the constant wall temperature condition, an experimental setup was designed as presented schematically in Fig. 2.

The flow circuit has several parts including: test section, pre-cooler, reservoir tank, heat exchanger, gear pump, flow meter, differential manometer, thermocouples and flow control system. In the experiments, both types of smooth and microfin tubes were used whose specifications are presented in Fig. 3 and Table 1. The time required for the flow to become steady was about 15 min and the data were recorded after 30 min.

The test tube is located in a steam tank which keeps the tube wall at a constant temperature of 98 °C. The steam tank is insulated using fiberglass to reduce the heat losses. The cooling system of the setup has two stages. In the first stage, the cooling water is used to precool the nanofluid using a copper coil embedded in the reservoir tank. In the second one, the cooling water cools down the nanofluid flow to about 15 °C in a shell and tube heat exchanger. After initial cooling of the nanofluid inside the reservoir tank, it was pumped to the main line by a gear pump. As the gear pump speed is fixed, a bypass line was used to control the flow rate in the main line. Adjusting the flow rate is accomplished using a globe valve to bypass some of the flow to the reservoir tank. The main line flow rate is such that the flow is always in the laminar regime. In the test section, four thermocouples are installed at specified intervals to measure the tube wall temperature. In addition, two thermocouples are installed at the inlet and outlet of the test section to measure the inlet and outlet flow temperatures.

2.3. Instruments

To measure the nanofluid temperature in the test section inlet and outlet, two RTD PT 100 thermometers were used with the accuracy of ±0.1 °C. In addition, in order to ensure that the tube wall temperature is constant during the tests, four K-type thermocouples with the SU-105 KPR sensor were installed on the tube wall with the 10 cm interval. A PMD-75 pressure transmitter with the accuracy of ±0.075% was implemented to measure the pressure drop. To measure the flow rate, a 1000 ml scaled separation funnel was used. In this method, the flow rate may be directly measured by means of measuring the funnel filling time using a digital timer with the accuracy of 0.01 s.