Mixed Convection Heat Transfer of Copper Oxide-Heat Transfer Oil Nanofluid in Vertical Tube

Farhad Hekmatipour, M. A. Akhavan-Behabadi, Farzad Hekmatipour

***Abstract*—**In this paper, experiments were conducted to investigate the heat transfer of Copper Oxide-Heat Transfer Oil (CuO-HTO) nanofluid laminar flow in vertical smooth and microfin tubes as the surface temperature is constant. The effect of adding the nanoparticle to base fluid and Richardson number on the heat transfer enhancement is investigated as Richardson number increases from 0.1 to 0.7. The experimental results demonstrate that the combined forced-natural convection heat transfer rate may be improved significantly with an increment of mass nanoparticle concentration from 0% to 1.5%. In this experiment, a correlation is also proposed to predict the mixed convection heat transfer rate of CuO-HTO nanofluid flow. The maximum deviation of both correlations is less than 14%. Moreover, a correlation is presented to estimate the Nusselt number inside vertical smooth and microfin tubes as Rayleigh number is between 2´105 and 6.8´106 with the maximum deviation of 12%.

***Keywords*—**Nanofluid, heat transfer oil, mixed convection, vertical tube, laminar flow.

I. Introduction

It is believed that adding nanoparticles to the based fluid is an effective way to improve the fluid flow heat transfer coefficient. In the recent years, many studies have been conducted to investigate the heat transfer phenomena soild-liquid flows. Initially, the effect of using water-copper oxide nanofluid on convection heat transfer in smooth tube is assssed [1]. Experimental research on the heat transfer and the flow behavior of the aqueous suspensions of TiO_2 nanoparticles flowing upward through a vertical tube was performed in [2]. The results illustrated that the heat transfer coefficient and the pressure drop increase in both laminar and turbulent regimes. In other research, the effect of using Al_2O_3-water nanofluid on mixed convective heat transfer is evaluated in different angles between 0° and 75° [3]. The alteration of slope pipes was illustrated; even though, the nanoparticles concentration has no significant influence on the hydrodynamics of the flow, the heat transfer coefficient enhances substantially.

The Darcy friction factor increases monotonically with the inclination angle. However, the maximum heat transfer coefficient is seen at the angle of 45°. Experiment on the mixed convection heat transfer of the water-Al_2O_3 nanofluid flow in inclined tubes has been performed in [4]. The result demonstrates that due to adding nanoparticles, Nusselt number and the pressure drop increase 13.6% and 0.1%, respectively. Laminar flow of nanofluids and vertical pipe can affect natural convection [5]. The maximum deviation of the correlation was 10%. In another research, an experiment on the convection heat transfer of the oil based- CuO nanofluid flow inside inclined tubes has been conducted [6]. The maximum heat transfer coefficient enhancement was reported at the nanoparticle mass concentration of 2% and the tube angle of 30°, which was equal to 15.2%. Combined free and forced convection heat transfer of MWCNT-HTO nanofluid has been investigated experimentally [7]. The performance index of the tested microfin and smooth tubes have been assessed in this work. The performance index illustrates that the use of adding nanoparticle to based fluid can be more beneficial than the increment of pressure drop. The result demonstrated that heat transfer increases up to 4% and 8% in smooth and microfin tubes, respectively.

After reviewing a variety of the prior literatures, it was comprehended that there are a few investion on mixed convection heat transfer of nanofluid in an upward flow under isothermal tubes. The aim of this research is the determination of mixed convection and pressure drop of copperoxide-heat transfer oil in slope microfin tube. The surface temperature of the microfin tube is constant and the flow rate is low enough to ensure that the flow regime maintains laminar.

II. Experimental Study

A. Nanofluid Properties

Due to the fact that the suspension of CuO and HTO is almost stable in period of experiments, ultrasonic UPS400 with the frequency of 24 kHz and the power of 400 W was utilized. To obtain reliable results, three concentrations of nanofluids were made with copper nanoparticles. The range of mass concentration suspensions was from 0.5 to 1.5%. The nanofluids were stable for 216 hr, and then the nanoparticles started to precipitate and settled down completely after 14 days.

B. Test Setup

The experimental setup is presented in Fig. 1. During the experiments, a vertical smooth tube is used whose inner and outer diameters are 8.62 mm (0.3394 inches) and 9.52 mm (0.3748 inches), respectively The location of a test tube is in a steam tank to hold the tube wall at a fixed temperature of 98

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^{0}C (208.4 °F). Isolation of the steam tank is done utilizing fiberglass to decline the heat waste. Two steps are utilized to decline the temperature of nanofluid. A helical tube is put into nanofluid container to perform as initial heat exchanger due to the diminishing of nanofluid. Secondly, temperature of nanofluid decreases to reach 15 °C (59 °F) in a shell and tube heat exchanger. After initial cooling of the nanofluid inside the reservoir tank, it is pumped to the main line by a gear pump. As the gear pump speed is fixed, a bypass line is used to control the flow rate in the main line. The main line flow rate is such that the flow is always in the laminar regime.

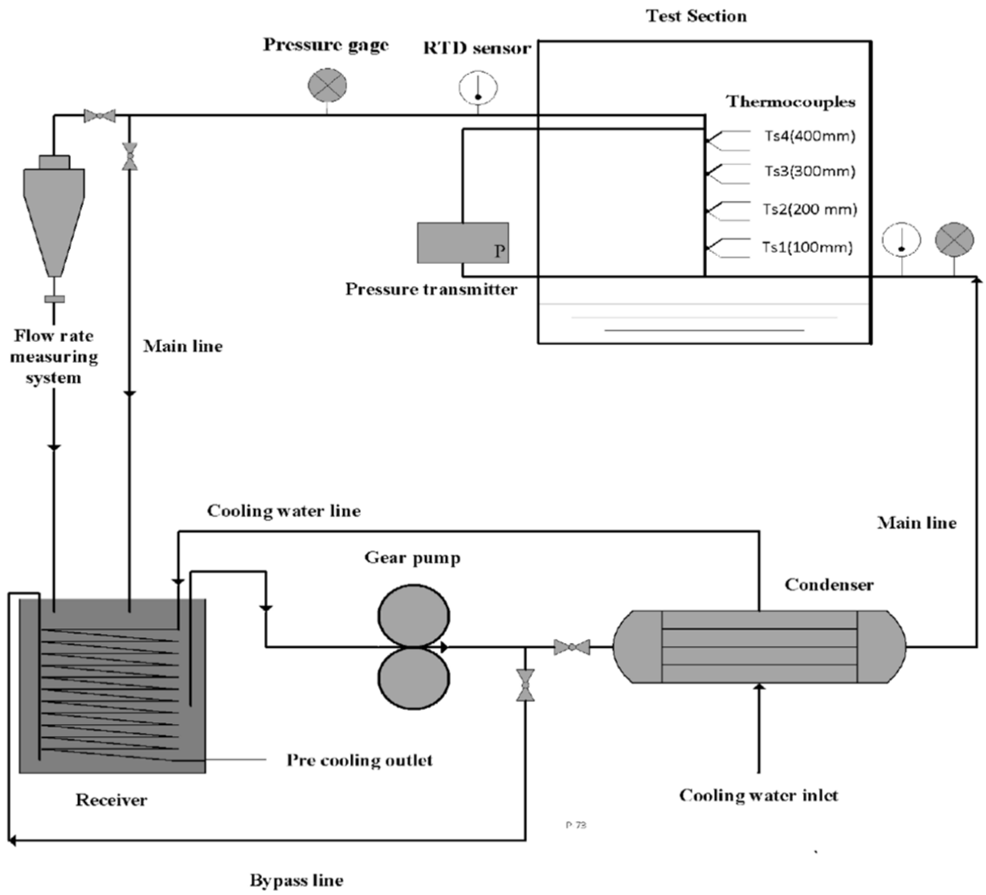

Fig. 1 Schematic of the test setup

C. 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, the SU-105 KPR sensors were joined four K-types thermocouple which are on the test section and the measurement of wall temperture is done by four thermocuples and sensors. Thus, the distance between two thermocouples is 10 cm. 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.

III. Result and Discussion

The assessment of the Nusselt number of the nanofluid flow in the microfin tube is calculated by:

$$\mathrm{Nu_{exp}} = (\dot{m}C_p)/(\pi Lk)\ln\left(T_w - T_{b,i}/T_w - T_{b,o}\right) \qquad (1)$$

The microfin tube hydraulic diameter may be calculated as [10]:

$$D_h = \ 2R/\left(((Nz)/\pi) + 1\right) \qquad (2)$$

To evaluate the results, the experimental mixed convection Nusselt number of the pure HTO flow is compared with the predicted Nusselt in Fig. 2.

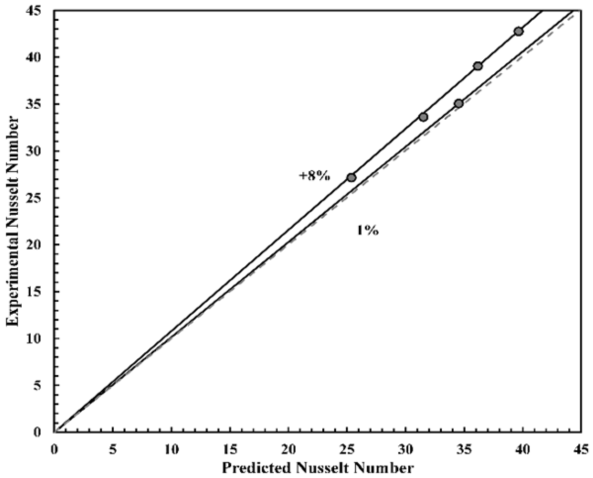

Fig. 2 Comparison of the experimental data with the classic correlations

A. Circular Tube

The laminar flow is hydro-dynamically fully developed and the ratio of Reynolds number rised up to 730 in this research. Fully hydraulic developed length is obtained (L< 0.05ReD) and fully thermally developed lengths are acquired (L < 0.058RePrD). Maximum deviation of the experimental results of the Nusselt number is about 8% on Fig. 2. Experimental results are in good agreement with the classical Eubank and Proctor's correlation. Although the flow is hydro-dynamically fully developed, it is on the thermal entrance region. As a consequence, the entrance effects should be taken into account to evaluate the nanofluid flow heat transfer rate. As shown in Fig. 3, Nusselt number increases along with Graetz number as much as the nanoparticles concentration. The maximum Nusselt number is seen in the nanopaticle concentration of 1.5%; which leads to 16% enhancement with respect to the base fluid flow.

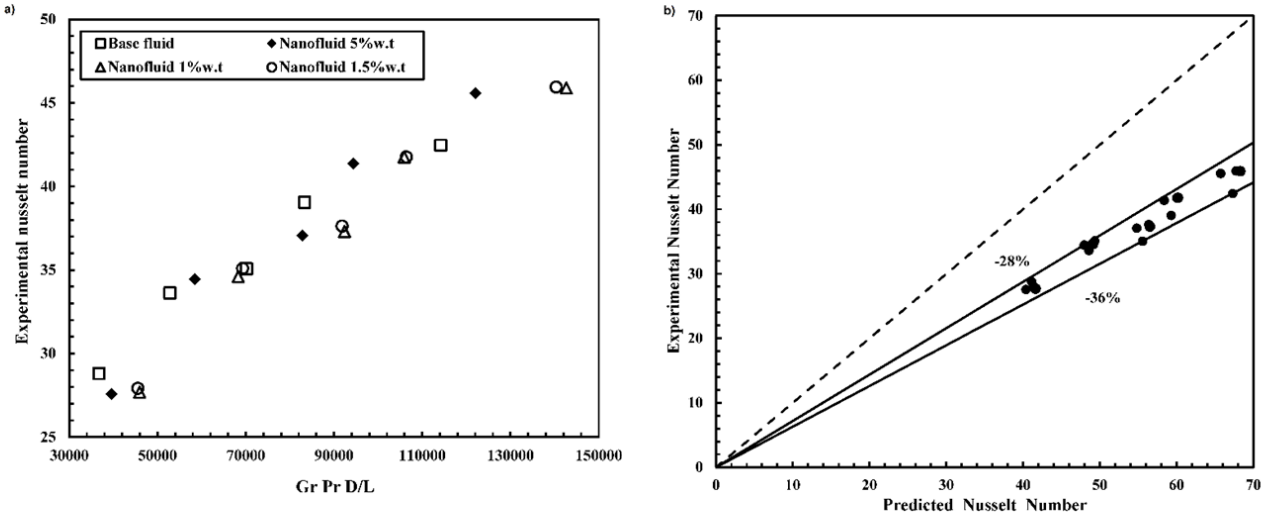

Fig. 3 (a) The effect of using CuO nanoparticles on the Nusselt number of the nanofluid flow in vertical tube (b) comparison of the experimental Nusselt number on horizontal tube and the nanofluid flow with the predicted equation [8]

The new experimental correlation is introduced as:

$$Nu = 1.8\left(\frac{\mu_b}{\mu_w}\right)^{0.14}\left[Gz + 0.12\left(\frac{RaD}{L}\right)^{0.44}\right]^{1/2} \quad (4)$$

Fig. 4 compares the experimental Nusselt number with the correlation prediction. As the maximum error is 10%, the presented correlation is completely appropriate to evaluate the mixed heat transfer coefficient of the nanofluid flow in vertical tubes, provided that the thermo-physical properties of the nanofluid are used to evaluate Graetz, Rayleigh and Nusselt number.

B. Microfin Tube

Fig. 5 shows that both nanoparticle concentration and Rayleigh number lead to enhance the mixed convection heat transfer rate in vertical microfin tubes. The Nuesselt number enhances up to 57, which is observed in the nanopaticle concentration of 1.5% and the Rayleigh number 680000.

Due to the evaluation of experimental result, an equation is introduced to evaluate the heat transfer rate in vertical microfin tube. The equation is as follows:

$$Nu = 1.75\,(\mu_b/\mu_w)^{(0.14)}(Gz + 9(Ra\,D/L)^{0.5})^{(1/3)} \quad (5)$$

The comparison of the experimental data with the results of (4) is demonstrated in Fig. 5. As the maximum deviation is 14%, the presented correlation is completely reliable to be used for estimating the latest of experimental and numerical research.

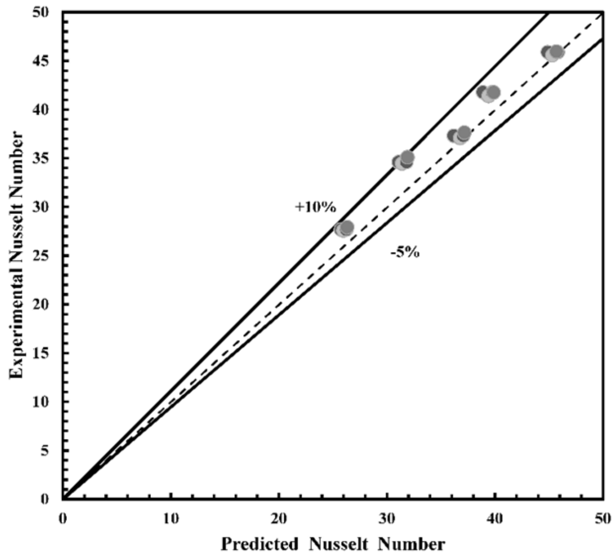

Fig. 4 Comparison of the experimental Nusselt number with the correlation prediction

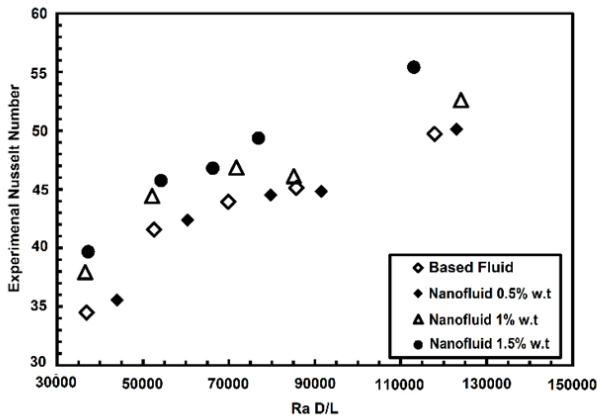

Fig. 5 The effect of using CuO nanoparticles on the Nusselt number of the nanofluid flow in vertical microfin tubes

IV. Conclusion

In this research, the effect of adding CuO nanoparticles on the mixed convection heat transfer rate of the HTO flow in vertical tubes was investigated experimentally. Using nanoparticles, the mixed convection Nusselt number may be increased up to 57%. Two new correlation was also presented to predict the Nusselt number. As the maximum error of the correlations is about 14%, it is reliable to estimate the heat transfer rate of the nanofluid flow with the reasonable accuracy.

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Nomenclature

D	=	tube diameter (m)
Gz	=	Graetz number (RePr D/L)
k	=	thermal conductivity (W/m.K)
L	=	tube length (m)
Ra	=	Rayleigh number

A. Greek

μ = Dyanimc viscosity

B. Subscripts

b_f	=	base fluid
n_f	=	nanofluid
w	=	wall

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