Experimental on Free and Forced Heat Transfer and Pressure Drop of Copper Oxide-Heat Transfer Oil Nanofluid in Horizontal and Inclined Microfin Tube

F. Hekmatipour, M. A. Akhavan-Behabadi, B. Sajadi

Abstract**—**In this paper, the combined free and forced convection heat transfer of the Copper Oxide-Heat Transfer Oil (CuO-HTO) nanofluid flow in horizontal and inclined microfin tubes is studied experimentally. The flow regime is laminar, and pipe surface temperature is constant. The effect of nanoparticle and microfin tube on the heat transfer rate is investigated with the Richardson number which is between 0.1 and 0.7. The results show an increasing nanoparticle concentration between 0% and 1.5% leads to enhance the combined free and forced convection heat transfer rate. According to the results, five correlations are proposed to provide estimating the free and forced heat transfer rate as the increasing Richardson number from 0.1 to 0.7. The maximum deviation of both correlations is less than 16%. Moreover, four correlations are suggested to assess the Nusselt number based on the Rayleigh number in inclined tubes from 1800000 to 7000000. The maximum deviation of the correlation is almost 16%. The Darcy friction factor of the nanofluid flow has been investigated. Furthermore, CuO-HTO nanofluid flows in inclined microfin tubes.

Keywords**—**Nanofluid; heat transfer oil; mixed convection; inclined 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 in nanofluid flows. For the first time, Lee et al. [1] conducted an experimental investigation on the nanofluid flow using CuO particles in the water base fluid. He et al. [2] performed an experimental research on the heat transfer and the flow behaviour of the aqueous suspensions of TiO_2 nanoparticles flowing upward through a vertical tube. They reported that the heat transfer coefficient and the pressure drop increase in both laminar and turbulent regimes. Akbarinia et al. [3] and Mirmasoumi and Behzadmehr [4] performed a numerical study on the fully developed laminar mixed convection heat transfer of water-Al_2O_3 nanofluid in tubes where the inclination angle was changed between 0 to 75°.

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 heat transfer coefficient reached the peak at the angle of 45°. Momin [5] conducted an empirical study on the mixed convection of the water-Al_2O_3 nanofluid flow in inclined tubes. He reported that due to adding nanoparticles Nusselt number and the pressure drop increases 13.6% and 0.1%, respectively. Guo et al. [6] conducted an experimental investigation on improved correlations of the effect of natural convection on laminar flow of nanofluids has conducted. The maximum deviation of the correlation was 10%. Recently, Pirhayati et al. [7] conducted an experimental research on the convection heat transfer of the oil copper oxide nanofluid flow inside inclined tubes. The maximum heat transfer coefficient enhancement was reported at the nanoparticle concentration of 2% and the tube angle of 30°, which was equal to 15.2%. Derakhshan et al. [8] conducted an experiment on the rheological characteristic and mixed convection heat transfer characteristic of multi walled carbon nanotube (MWCNT) heat transfer oil based nanofluid inside smooth and microfin tubes. The performance index of the tested microfin and smooth tubes has been assessed in this work. The performance index illustrates that heat transfer has been enhanced by using techniques. The result demonstrated that heat transfer increases up to 4% and 8% in smooth and micro-fine tube, respectively.

After reviewing a variety of the prior literatures, it was comprehended that there is lack of numerical and experimental studies on mixed convection heat transfer of nanofluid in horizontal and inclined microfin tubes. The objective of the experimental investigations is performed to examine the effect of adding nanoparticle the combined free and forced convection heat transfer and pressure drop of the CuO- HTO nanofluid flow in the inclined 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

In this study, spherical solid particles of copper oxide with the average size of 40 nm and the purity of 99% were used as nanoparticles. In order to obtain a homogeneous and a relatively stable nanofluid, an ultrasonic UPS400 with the frequency of 24 kHz and the power of 400 W was used. In this study, three samples of nanofluids were prepared. They include suspension of the heat transfer oil-copper oxide with the mass concentration of 0.5, 1, and 1.5%. The nanofluids

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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 horizontal and inclined microfin tube is used where inner and outer diameters are 8.62 and 9.52 mm, respectively. In addition, specifications of the microfins are presented in Table I. 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. Two stages are designed for this test setup because the gear pump is protected. Firstly, the water which comes from heat exchanger is utilized to reduce the temperature of the fluid using a coil putting into the receiver. Secondly, the water is used to decline the temperature of nanofluid to reach approximately 15 °C in a shell and tube heat exchanger. When the nanofluid is inside the receiver, a gear pump is used to be transferred nanofluid into main line. The gear pump has constant speed, and the by-pass line is designed to create several flow rate in test setup. The main line flow rate is such that the flow is always in the laminar regime.

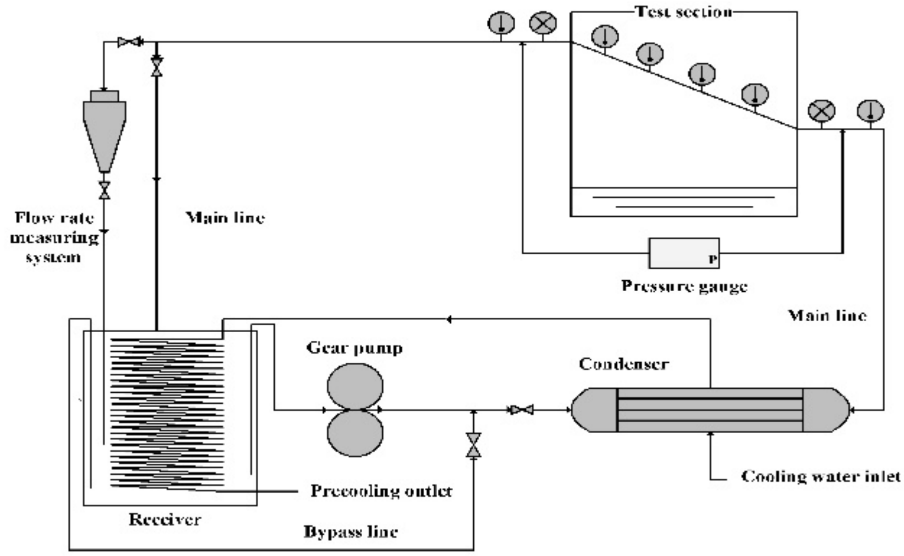

Fig. 1 Schematic of the test setup

TABLE I
SPECIFICATIONS OF THE MICROFIN TUBE

Parameter	Value
Fin height (mm)	0.2
Fin pitch (mm)	0.45
Number of fins	60
Helix angle (γ)	18
Vertex angle (θ)	24

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, four K-type thermocouples with the SU-105 KPR sensor were installed on the tube wall. The surface of tube divided five parts is due to the installation of thermocouples. Thus, this 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 Darcy friction factor and the Nusselt number are used to predict the pressure drop of nanofluid flow and heat transfer coefficient, respectively:

$$f_{exp} = (\pi^2 \rho D^5/(2L\dot{m}^2))\Delta p \quad (1)$$

$$\mathrm{Nu_{exp}} = (\dot{m}C_p)/(\pi L k)\ln\left(T_w - T_{b,i}/T_w - T_{b,o}\right) \quad (2)$$

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

$$D_h = 2R/\left(((Nz)/\pi) + 1\right) \quad (3)$$

To validate the results, the experimental Darcy friction factor and mixed convection Nusselt number of the pure heat transfer oil flow inside horizontal isothermal smooth tubes are compared with the results of classic Hagen-Poiseuile [9] and Jackson et al. [10], respectively. The maximum deviation of the experiment for the pressure drop and the heat transfer rate is almost 14% and 9%, respectively.

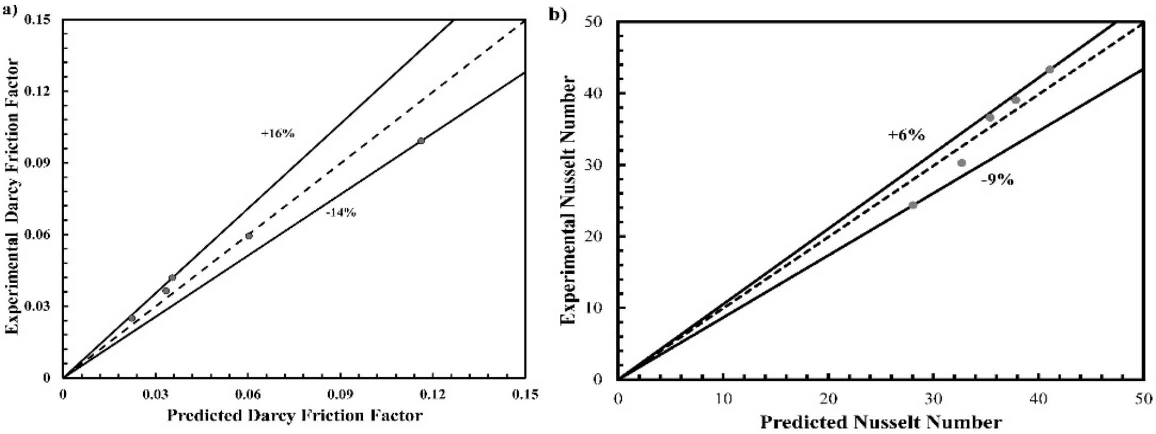

Fig. 2 Comparison of the experimental data with the classic correlations: (a) Darcy friction factor; (b) Nusselt number

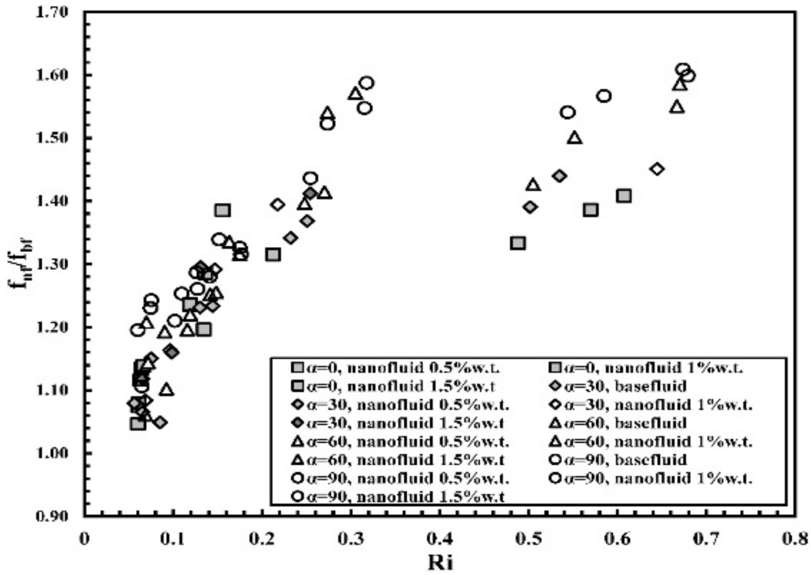

Fig. 3 The effect of using CuO nanoparticles on the Darcy friction factor of the nanofluid flow in the inclination round tubes based on the Darcy friction factor (α=0, 30, 60, 90)

A. Pressure Drop

Fig. 3 demonstrates the effect of adding copper oxide nanoparticles on the friction factor of the nanofluid flow in inclined isothermal tubes. According to the picture, the increment of the Richardson number and the mass concentration of nanoparticles leads to rise the Darcy friction factor. This might be either reduction of boundary layer owing to using the finned tube and the nanoparticles Brownian motion. Furthermore, those are able to increase both of the velocity profile uniform and the share wall stress. The maximum of the Darcy friction factor rate rises up to 70%.

To assess experimental results of the Darcy friction factor of the CuO-HTO nanofluid in microfin tube, a new correlation is proposed which is calculated based on the Darcy friction factor of the pure oil heat transfer. The following correlation is presented to assess the Darcy friction factor of the HTO-CuO nanofluid flow:

$$f_{nf}/f_{bf} = 1.2\left(1+\cos(\theta)\right)^{0.1}(1+\varphi)^{0.75}Ri^{0.08}(\mu_b/\mu_w)^{0.14} \quad (4)$$

Comparison between the experimental results and predicted value is illustrated in Fig. 4. In this figure, the maximum deviation of the correlation is almost 16%. As a consequence, the suggested correlation is able to predict the experimental results of the Darcy friction factor.

B. Heat Transfer

1) Horizontal Tube

Due to substantial improvement on heat transfer rate, the fluid flow makes changes inside microfin tube [10]. Fig. 5 illustrates the effect of adding CuO nanoparticles on mixed heat transfer rate of the nanofluid flow in horizontal and inclined microfin tube. This figure also shows the geometric change, and adding nanoparticle is likely to led to enhance the mixed convection in microfin tube. As shown the figure, the maximum of Nusselt number is seen in the nanoparticle mass concentration 1.5% and Richardson number 0.7. In addition, spiral fin and nanoparticle may be led to create the rotating flow in microfin tubes. Accordingly, this might give the velocity and share number of the nanofluid flow in wall stress. Moreover, according this figure, a new correlation is introduced to evaluate the effect adding copper oxide nanoparticle to oil heat transfer on combined free and forced convection in the horizontal microfin tube, as follows:

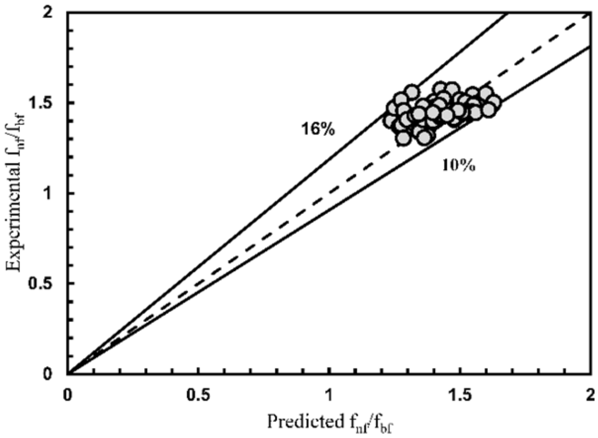

Fig. 4 Comparison of the experimental Darcy friction factor of the nanofluid flow with the prediction of (4) inside inclination microfin tube (α=0, 30, 60, 90)

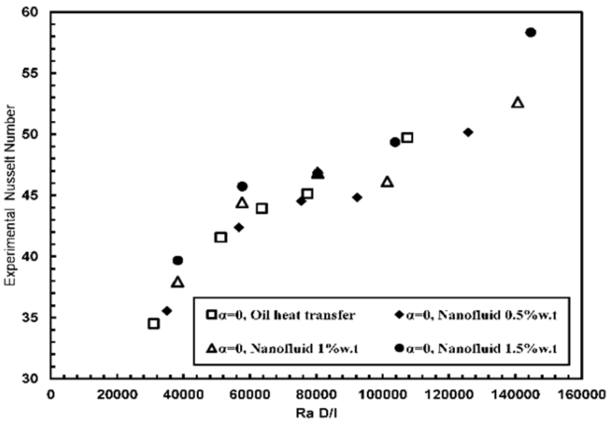

Fig. 5 The effect of using CuO nanoparticles on the Nusselt in horizontal microfin tubes

$$Nu = 1.75\,(Gz + 9(Ra\,D/L)^{0.54})^{(1/3)} \quad (5)$$

Comparison of the experimental result of the mixed convection of the HTO-CuO nanofluid flow with the prediction of (5) is shown in Fig. 6. Accordingly, the maximum deviation of the correlation is relatively almost 8%. Thus, the accuracy of the correlation is completely reliable to use for contrast between the experimental results and numerical results. In addition, new correlation is proposed what based on Richardson number is made. The effect of mixed convection is proposed and it is normalized with the forced convention in a horizontal microfin tube. The correlation is presented as:

$$Nu = 0.65(1 + (Ri)^{0.16})^{0.48}(\mu_b/\mu_w)^{0.14} \quad (6)$$

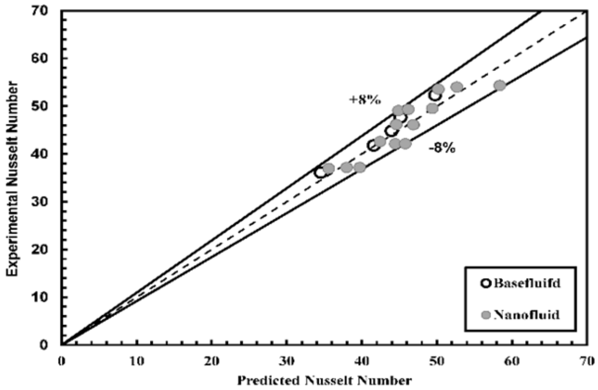

Fig. 6 Comparison of the experimental mixed heat transfer of the nanofluid flow with the prediction of (5)

Fig. 7 indicates that the maximum deviation of the correlation is approximately 9%. As a consequence, this correlation can be used for comparing the free and forced convection inside inclined microfin tube.

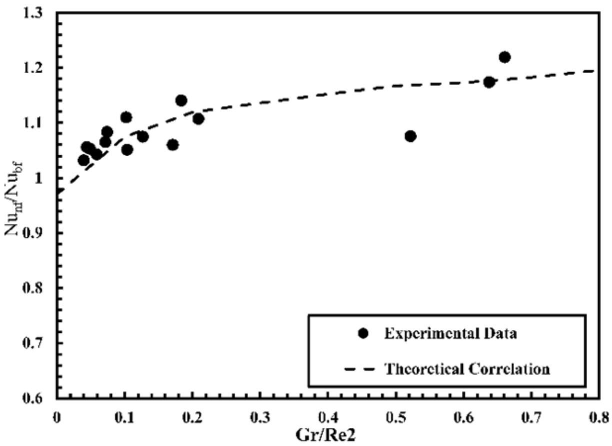

Fig. 7 Comparison of the experimental Nusselt number of the nanofluid flow with the prediction of (6)

2) Microfin Tube

Fig. 8 demonstrates the effect of adding copper oxide and spiral fin on free and forced heat transfer rate of the nanofluid flow in the inclined microfin tube. This image illustrates the geometric change and using copper nanoparticle improves the mixed convection in microfin tube. According to the picture, the maximum of Nusselt number can be seen in the nanoparticle mass concentration 1.5% and Rayleigh number 150000. Furthermore, characteristic of geometry and nanoparticle might make the rotating flow in microfin tubes. Accordingly, this might be created the velocity and share wall stress.

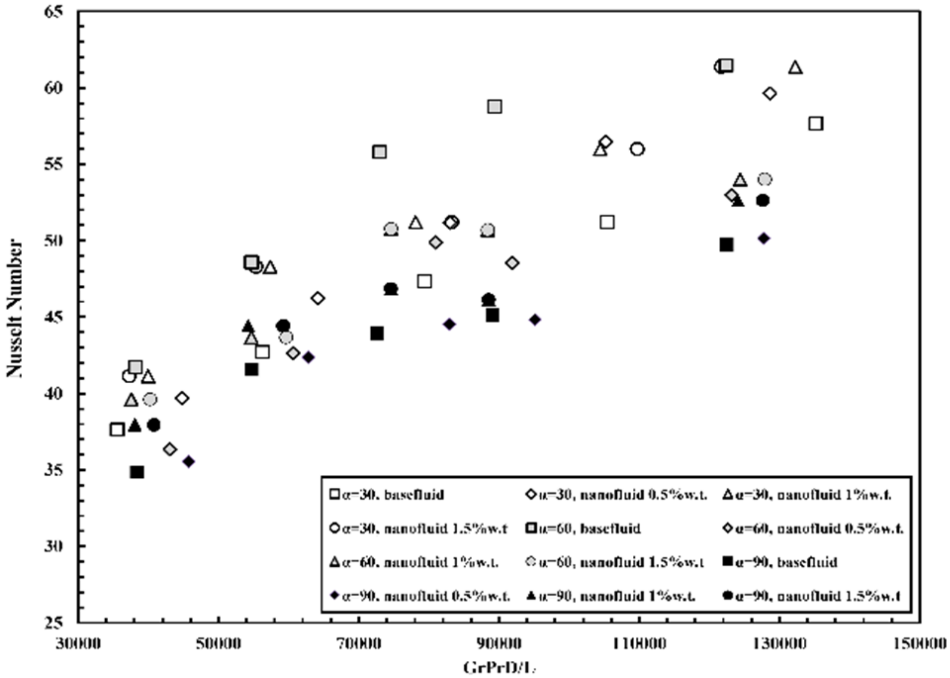

Fig. 8 The effect of using CuO nanoparticles on the Nusselt number of the nanofluid flow in the inclined microfin tube

Moreover, a new correlation is defined to estimate the influence of adding copper oxide nanoparticle to pure heat transfer oil on combined free and forced convection in an inclined microfin tube, as:

$$Nu = 1.75\big(1 + Cos(\theta)\big)^{0.1}(1+\varphi)^{0.9}(Gz + 9(Ra\ L/D)^{0.56})^{(1/3)}(\mu_b/\mu_w)^{0.14} \quad (7)$$

The experimental Nusselt number of the HTO-CuO nanofluid flow is contrasted with the prediction of (7) in Fig. 9. Because the maximum deviation is relatively almost 15%, the presented correlation is completely appropriate to estimate the mixed Nusselt number for the nanofluid flow inside inclined microfin tubes. Hence, it might be utilized to compare the mixed convection heat transfer with the numerical result.

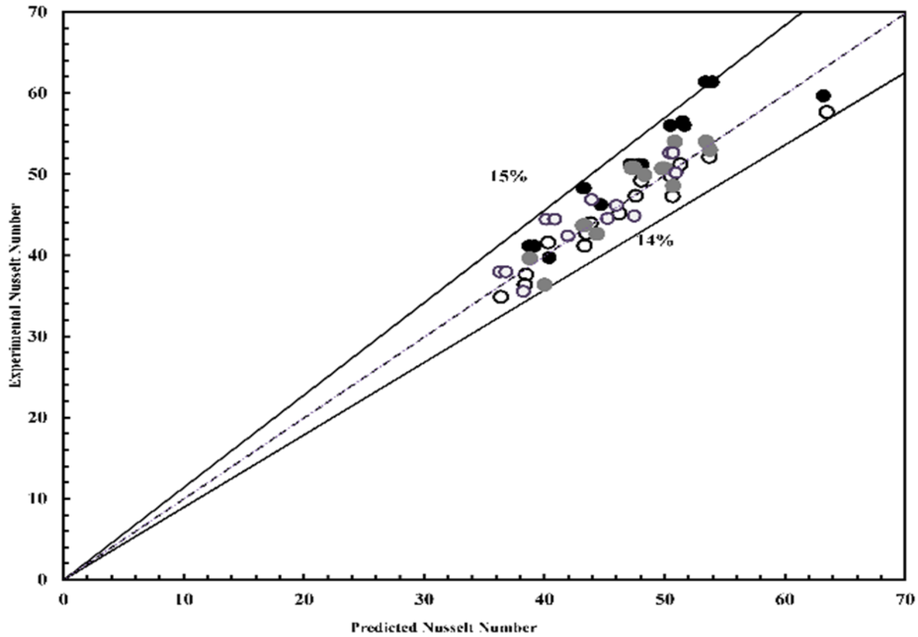

Fig. 9 Comparison of the experimental mixed convection heat transfer of the nanofluid flow with the prediction of (7)

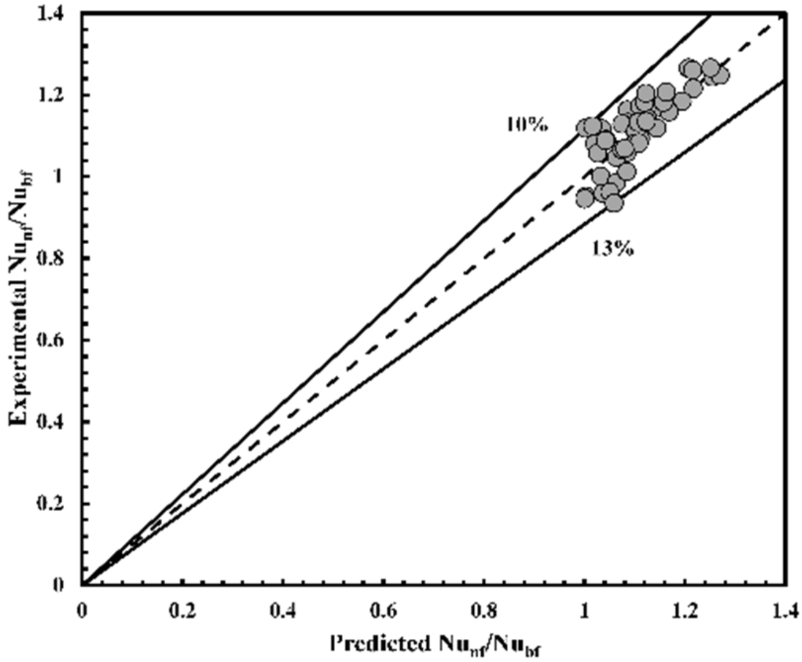

Fig. 10 Comparison of the experimental Nusselt number of the nanofluid flow with the prediction of (8)

Furthermore, correlation is proposed based on Richardson number and the influence of the mixed convection to make the impact of the mixed heat transfer of nanofluid and it is normalized by the force convection. This correlation is presented as follows:

$$\frac{Nu_{nf}}{Nu_{bf}} = 0.92\,\left(1+Cos(\theta)\right)^{0.1}(1+\varphi)^{0.6}(\mu_b/\mu_w)^{0.14}\left[1+(1+(Ri)^{0.1}\right]^{0.1} \quad (8)$$

Fig. 10 compares the experimental Nusselt number of the HTO-CuO nanofluid flow with the prediction of (8).

The maximum error of the correlation is around 11%. Therefore, the correlation might be gained to evaluate the impact of the combined natural and forced heat transfer of the nanofluid in an inclined microfin tube with an appropriate accuracy.

C. Performance Index

Heat transfer enhancement methods accompany with increases in the pressure drop. In order to assess the impact of heat transfer and pressure drop, the performance index can be identified as:

$$\eta = (\,\bar{h}_{nf}\Delta P_{bf}/\bar{h}_{bf}\Delta P_{nf}) \quad (9)$$

The performance index bigger than one illustrates that enhancement of heat transfer is larger than the increment of pressure drop.

The performance index of the system can be assessed by using the heat transfer rate and the pressure drop rate of the pure heat transfer oil and the nanofluid flow. Fig. 11 demonstrates the influence of the Richardson number in the performance index as the nanoparticles mass concentration increases from 0.5 to 1.5%. In this figure, it also shows that the performance index is not always larger than unity. The maximum performance index of nanofluid is 1.65% which is obtained by nanoparticles mass concentration of 1.5% and an angle of 30°. In addition, it is observed that the minimum of the performance index is occurring in inclined tube and base fluid.

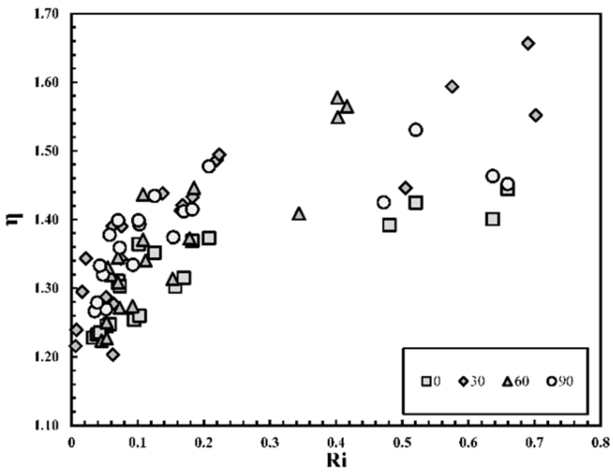

Fig. 11 The performance index of HTO-CuO nanofluid flow in horizontal and inclined microfin tube

IV. Conclusion

In this research, the effect of adding copper nanoparticles to heat transfer oil on the mixed convection heat transfer rate and pressure drop in an inclination circular and the microfin tube was investigated experimentally. The result might be summarized as follows:

In horizontal microfin tube, adding copper oxide nanoparticle leads to improve the combined free and forced convection which is about 21% and is seen at the nanoparticle mass concentration 1.5% and Richardson number 0.7. A couple of new correlation are introduced to predict the effect of adding nanoparticle to oil heat transfer inside horizontal microfin tube. The correlations are adequate accuracy because the maximum deviations are lower than 10%.

In inclined microfin tube, the results show that the enhancement of the mixed convection heat transfer, due to adding the copper oxide nanoparticle to the pure oil heat transfer, was relatively approximately 28%. In addition, two new correlations were identified to predict the mixed Nusselt number in inclined microfin tube, and the maximum deviation of the mixed convection heat transfer is as lower as 15%.

In inclination microfin tube, the spiral fin and adding copper oxide to oil heat transfer lead to increase the Darcy friction factor to reach 70%. The assessment of the Darcy friction factor with a correlation was calculated based on the experimental results which can predict the CuO- HTO flow in inclined microfin tubes with the maximum deviation of 15%.

The system performance index was evaluated to compromise the effect of nanoparticles of the heat transfer rate. The majority of results were larger than unity which indicates that using nanoparticles is more in favor of heat transfer improvement rather than in pressure drop increment. The performance index was 1.65%, which is obtained in the nanoparticle concentration of 1.5% and Richardson number of 0.7, in circular tube and microfin tube, respectively.

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