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An Experimental Investigation on the Convective Heat Transfer Coefficient and Nusselt Number in Water/Carbon Nanofluid

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ABSTRACT: The heat transfer coefficient of fluid is one of the most important effective factors on the performance of fluid in the heat transfer process. Due to the higher conductive heat transfer coefficient of metals than liquids, metal particles can be used to increase the heat transfer rate of liquids. Nanofluid is one of the novels and developing methods to improve the heat transfer rate in heat exchangers. In this paper, the main effective parameters (flow rate and concentration) on increasing the convective heat transfer coefficient of water carbon nanofluid compared with water as a base fluid, are investigated in the Reynolds range of 7,100 to 16,700. The results illustrate that increasing the Re leads to increase in the Nusselt number and convective heat transfer coefficient, and also to decrease the friction factor. It is also shown that at a constant *Re*, carbon nanofluid is able to enhance the convective heat transfer coefficient up to 10.17%, compared with pure water. It is found that adding carbon nanoparticles to water, initially leads to increasing the convective heat transfer coefficient, while this trend continues until the concentration of about 0.2 wt%, and then has a descending trend. In addition, the pressure drop was investigated due to changes in Re and was shown that the behavior of this curve is in agreement with Moody's diagram.

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1. INTRODUCTION

Due to the proven potential of nanoparticles to enhance the heat transfer coefficient of the base fluid, extensive researches are being processed in this field. These researches have wide branches in different sciences e.g. agriculture [1], medical [2], renewable energy [3], etc. In an experiment, Jung et al. [4] used aluminum oxide in water as a nanofluid. It was investigated in a rectangular microchannel in laminar flow and an increase of 32% was reported in the convective heat transfer coefficient. In another study, Wen and Ding [5] focused on investigating the heat transfer of 1.6 vol% of aluminum oxide, in the entrance region of a tube. Finally, they reported a 41% enhance in the convective heat transfer coefficient. Paryani and Ramazani [6], experimentally investigated the effect of TiO_2 in water, at Reynolds range of 11,000 to 21,000. They showed that this nanofluid has the best heat transfer behavior in the concentration of 0.02 vol%. Haghighi et al. compared the convective heat transfer coefficient for three different nanoparticles, include CuO, TiO_2 and Al_2O_3 in turbulent flow. Goozatloo et al. had an experimental study on Ethylene-Glycol/Graphene nanofluid with weight concentration of 0.1% and more than 42% increase in convective heat transfer was reported, compared with the base fluid.

Although adding nanoparticles leads to enhance the rate of heat transfer, but has a negative effect on the flow pressure drop in the tube. Hence, the pressure drop issue is another important topic that is considered by scholars. Saeedinia et al. [7], performed a study on pressure drop of CuO/oil nanofluid. They showed a 63% increase in pressure drop when CuO/oil nanofluid flows through a tube in a laminar flow. In another similar research, Hussein et al. [8] investigated the effect of adding 0.017 vol% of graphene to Al_2O_3/water nanofluid and observed a 15% increase in pressure drop.

According to the above literature review, in this study, the effect of using carbon-black nanoparticles in water, on both heat transfer and pressure drop, is considered. It should be noted that a coiled tube heat exchanger has been used. Experiments are carried out in a turbulent regime and at Reynolds range of 7,100 to 16,700.

2. METHODOLOGY

2.1. Governing equations

Since the effect of adding nanocarbon to water on heat transfer and pressure drop of water is investigated experimentally, the following relations should be introduced to calculate the Nusselt number and friction factor as two important non-dimensional engineering characteristics. In order to calculate the *Nu*, we should find the average convective heat transfer coefficient (*h*) as follows:

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$$h = \frac{q''}{T_w - T_f} \quad (1)$$

where,

$$q'' = \frac{\bar{q}}{\pi D_{out} L} \quad (2)$$

In the above equations, T_w and T_f are the wall and fluid temperatures, respectively. D_{out} and L are the geometrical parameters of the coil, which are the outer diameter and the length of the coiled tube, respectively. Moreover, $\bar{q}$ is the average quantity of the heat transferred to the fluid and could be calculated as:

$$\bar{q} = \frac{q_1 + q_2}{2} \quad (3)$$

where:

$$q_1 = V.I \quad (4)$$

and;

$$q_2 = \dot{m} c_p (T_{out} - T_{in}) \quad (5)$$

In Eqs. (4) and (5), V is the voltage of the heaters in V and I is the electrical current in A. Furthermore, $\dot{m}$ is the flow rate of nanofluid in kg/s, C_p is the specific heat capacity of the nanofluid in J/kg K. T_{in} and T_{out} are input and output temperature of nanofluid in (°C). Therefore, the mean value of *Nu* could be calculated as:

$$\overline{Nu} = \frac{hD_{in}}{k} \quad (6)$$

In order to calculate friction factor, Eq. (7) which is known as Darcy–Weisbach equation is used:

$$f = \frac{\Delta P}{\left(\frac{L}{D_{in}}\right)\left(\frac{\rho u^2}{2}\right)} \quad (7)$$

2.2. Experimental procedure

In this study, different weight concentrations of nanocarbon in water include: 0.1, 0.2, 0.3 and 0.4 percent were tested. In order to achieve better stability of carbon in water, a surfactant should be used. In the present study, Sodium-Dodecyl-Sulfate (SDS), with the chemical formula of $NaC_{12}H_{25}SO_4$ has been used. The chemical characteristics of nanocarbon and SDS, are listed in Table 1. Carbon nanoparticles and SDS were mixed by the ratio of 1:1 in water for about 30 minutes in a blender and then, the prepared nanofluid is placed in an ultrasonic device at a constant frequency of 20 Hz for about

Table 1. Chemical characteristics of carbon and SDS

Material	Specific heat capacity (J/kg K)	Density (kg/m^3)	Thermal conductivity (W/mK)
Carbon	709	2050	168
SDS	NA	1010	0.58

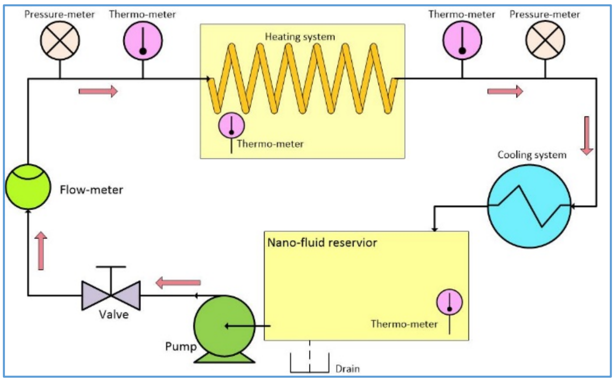

Fig. 1. Scheme of the experimental setup

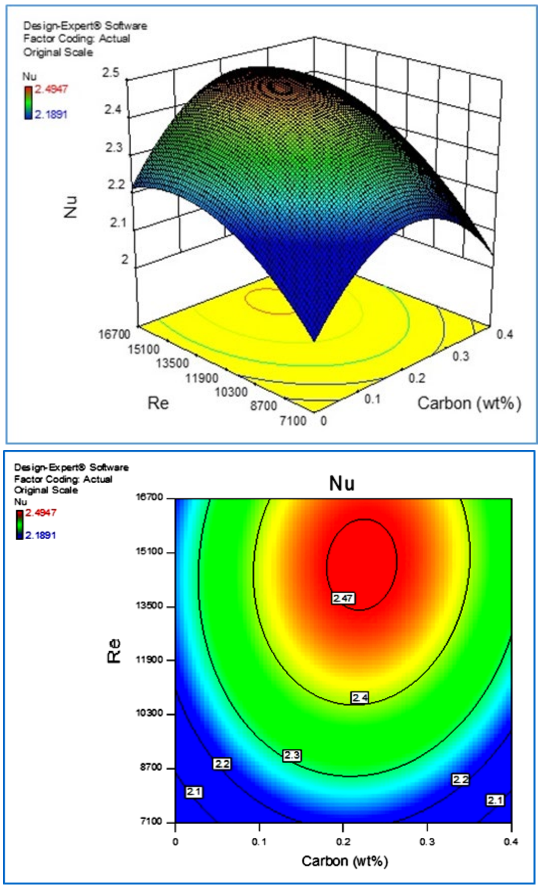

Fig. 2. The variations of *Nu* versus *Re* and nanofluid concentration

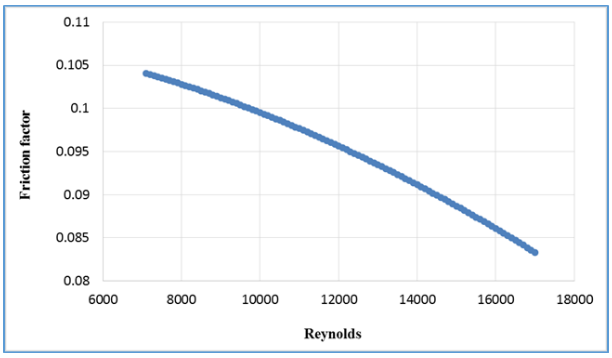

Fig. 3. The variation of friction factor versus *Re*

30 minutes. A schematic view of the experimental set-up has been shown in Fig. 1. The reservoir has a maximum capacity of 25 liters. The flow circulation was done by a 1-HP pump. This pump can provide the flow rate range of 1 lit/min to 8 lit/min. In the heating part, an electric element with a power of 1.5 kW has been used.

In this experiment, flow rates of 3 to 7 lit/min are applied. Each test continues until temperature difference reaches a steady value. It should be noted that each experiment has been done twice and the repeatability of experiments is satisfied. Totally, 11 experiments were done and the interval data are obtained by Design Expert software. This software uses estimation and statistical methods. In this project, the differences between experimental results and Design Expert calculations are less than 4.5%.

3. RESULTS AND DISCUSSION

3.1. Heat transfer

The variation of *Nu* number versus Reynolds has been depicted in Fig. 2. Clearly, by increasing in *Re*, the *Nu* is increased too. From a concentration viewpoint, until the weight concentration of 0.22 wt%, *Nu* is increased too, but afterward, the trend of *Nu* is reversed. The highest *Nu* is seen in Re of 14,850 and a concentration of 0.22 wt% with a value of 2.478.

The behavior of the Convective Heat Transfer Coefficient (CHTC) is completely similar to *Nu*. The highest CHTC with a value of 175.7 W/m^2K is seen in *Re* of 14,850 and a concentration of 0.22 wt%.

3.2. Pressure drop

The variation of friction factor with *Re* number has been shown in Fig. 3. Accordingly, the friction factor is decreased by increasing in *Re*. So, the highest friction factor is seen in the lowest *Re*. the trend of this figure is completely in agreement with Moody's diagram.

4. CONCLUSIONS

The main purpose of this study is to evaluate the convective heat transfer coefficient, *Nu* and pressure drop of different concentrations of carbon nanofluid in various Reynolds numbers. The results illustrate that in an optimum state, both *Nu* and convective heat transfer coefficient have been increased by 10.17 % compared with pure water. Furthermore, the reduction in pressure drop was more than 25% from *Re* of 7,100 to 16,700.

REFERENCES

[1] D. Chen, P. Szostak, Z. Wei, R. Xiao, Reduction of orthophosphates loss in agricultural soil by nano calcium sulfate, Science of The Total Environment, 539 (2016) 381-387.
[2] J. Ghodsi, A.A. Rafati, Y. Shoja, A novel biosensor based on horseradish peroxidase trapped in silica Sol-Gel/MWCNTs matrix for methyldopa determination in medical and pharmaceutical samples, Advances in Nanochemistry, 1(1) (2019) 6-11.
[3] M. Firoozzadeh, A.H. Shiravi, M. Shafiee, Experimental Study on Photovoltaic Cooling System Integrated With Carbon Nano Fluid, Journal of Solar Energy Research, 3(4) (2018) 287-292.
[4] J.-Y. Jung, H.-S. Oh, H.-Y. Kwak, Forced convective heat transfer of nanofluids in microchannels, in: ASME 2006 International Mechanical Engineering Congress and Exposition, American Society of Mechanical Engineers, 2006, pp. 327-332.
[5] D. Wen, Y. Ding, Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions, International Journal of Heat and Mass Transfer, 47(24) (2004) 5181-5188.
[6] S. Paryani, A. Ramazani SA, Investigation of the combination of TiO2 nanoparticles and drag reducer polymer effects on the heat transfer and drag characteristics of nanofluids, The Canadian Journal of Chemical Engineering, 96(6) (2018) 1430-1440.
[7] E.B. Haghighi, M. Saleemi, N. Nikkam, R. Khodabandeh, M.S. Toprak, M. Muhammed, B. Palm, Accurate basis of comparison for convective heat transfer in nanofluids, International Communications in Heat and Mass Transfer, 52 (2014) 1-7
[8] A. Ghozatloo, M. Shariaty-Niasar, A.M. Rashidi, Investigation of Heat Transfer Coefficient of Ethylene Glycol/ Graphenenanofluid in Turbulent Flow Regime, International Journal of Nanoscience and Nanotechnology, 10(4) (2014) 237-244

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