

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

Amir Hossein Shiravi<sup>1\*</sup>, Mojtaba Shafiee<sup>2</sup>, Hadis Bostani<sup>1</sup>, Mohammad Firoozzadeh<sup>1</sup>, Maryam Bozorgmehrian<sup>1</sup>

<sup>1</sup> Department of Mechanical Engineering, Jundi-Shapur University of Technology, Dezful, Iran

<sup>2</sup> Department of Chemical Engineering, Jundi-Shapur University of Technology, Dezful, Iran

## ABSTRACT

The heat transfer coefficient of a fluid is one of the most important effective factors on the performance of a fluid in the heat transfer process. Due to 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 novel and developing methods to improve 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 base fluid, are investigated in the Reynolds range of 7,100 to 16,700. The results illustrate that increasing the  $Re$  leads to increase 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 increase 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.

## KEYWORDS

Nanofluid, Heat transfer, Nusselt number, Friction factor

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\* Corresponding author Email: ahshiravi@jsu.ac.ir

## 1. Introduction

Due to the proved 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 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 41% enhancing in the convective heat transfer coefficient. Paryani and Ramazani [6], experimentally investigated the effect of TiO<sub>2</sub> 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<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> 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 negative effect on the flow pressure drop in tube. Hence, pressure drop issue is another important topic which is considered by scholars. Saedinia et al. [7], performed a study on pressure drop of CuO/oil nanofluid. They showed 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<sub>2</sub>O<sub>3</sub>/water nanofluid and observed 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 turbulent regime and at Reynolds range of 7,100 to 16,700.

## 2. Governing equations

Since the effect of adding nano carbon 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:

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

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 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 equations (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, equation (7) which is known as Darcy–Weisbach equation is used:

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

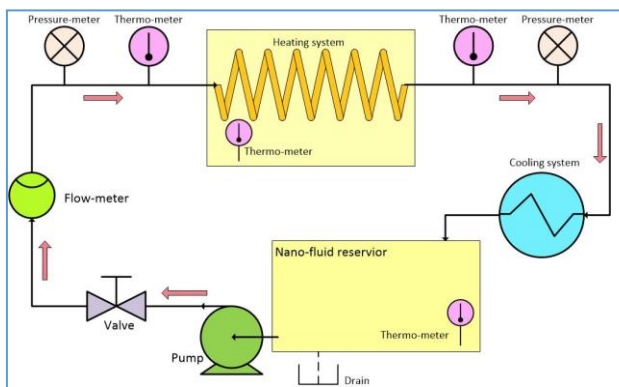
## 3. Experimental procedure

In this study, different weight concentrations of nano carbon in water include: 0.1, 0.2, 0.3 and 0.4 percent were tested. In order to achieve a better stability of carbon in water, a surfactant should be used. In the present study, Sodium-Dodecyl-Sulfate (SDS), with chemical formula of NaC<sub>12</sub>H<sub>25</sub>SO<sub>4</sub> has been used. The chemical characteristics of nano carbon and SDS, are listed in Table 1. Carbon nanoparticles and SDS were mixed by 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 30 minutes. A schematic view of the experimental set-up has been shown in Figure 1. The reservoir has 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.

**Table 1. Chemical characteristics of carbon and SDS**

Material	Specific heat capacity (J/kg K)	Density (kg/m <sup>3</sup> )	Thermal conductivity (W/mK)
Carbon	709	2050	168
SDS	n.a.	1010	0.58



**Figure 1. Scheme of the experimental setup**

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%.

## 4. Results and discussions

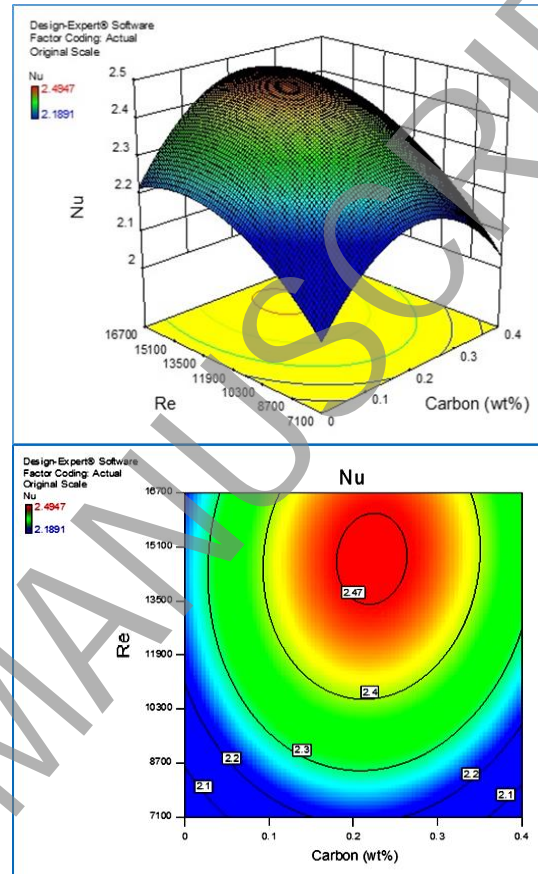
### 4.1. Heat transfer

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

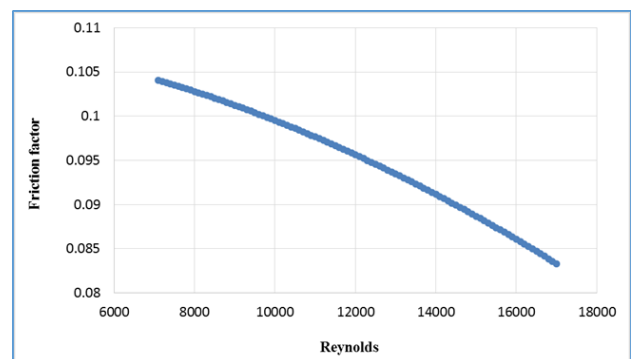
The behavior of convective heat transfer coefficient (CHTC) is completely similar to  $Nu$ . The highest CHTC with value of 175.7 W/m<sup>2</sup>K is seen in  $Re$  of 14,850 and concentration of 0.22 wt%.

### 4.2. Pressure drop

The variation of friction factor with  $Re$  number has been shown by Figure 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 the Moody's diagram.



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



**Figure 3. The variation of friction factor versus  $Re$**

## 5. 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 optimum state, both  $Nu$  and convective heat transfer coefficient have been increased 10.17 % compared with pure water. Furthermore, reduction in pressure drop was more than 25% from  $Re$  of 7,100 to 16,700.

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