

Experimental investigation on the enhancement of heat transfer by using carbon nanotubes CNT taunit m series

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Abstract. The enhancement of heat transfer is considered as one of the important tasks for controlling the energy dissipation and consumption. In order to secure this task, it is intended to increase the efficiency of heat exchanging systems taking into account the economic and environmental considerations. This work aims to test experimentally the effect of nanoparticle concentration functionalized carbon nanotubes (FCNT Taunit M) in water and Reynolds number on the heat transfer coefficient. Three concentrations of 0.01, 0.05, 0.1 vol.% for FCNT taunit have been used. The heat transfer augmentation of the nanofluid was investigated experimentally through a test rig constructed for this purpose under constant heat flux range (16061-22682) W/m² at the developing region with Reynold number range 5000, 7000 and 9000 have been used. The particle size 12 nm for FCNT Taunit M. The experimental results revealed an augmentation in the Nusselt number as the volume concentration increased. The economic aspect was taken into account in this study. Pressure drop can be neglected because the increases were very small.

1.Introduction

Nowadays, the location and importance of heat transfer in engineering applications such as heat exchangers, casting processes and cooling systems of electronic equipment is very much considered. Furthermore, traditional fluids such as oil, water, and ethylene glycol EG in general are used for heat transfer. Many of the techniques have been applied to improve heat transfer in cooling systems and heating, but the efficiency of these fluids in the heat transfer applications is low. Dispersion of solid particles in different fluids is a new method increase heat transfer. Using nanofluid is one of the best ways to improve the heat transfer, which was given by Choi [1]. Nanofluids are mixtures of nanometer-sized solid particles such as carbon nanotube (MWCNTs or SWCN, Titanium dioxide (TiO₂), Copper (II) oxide (CuO), Aluminium (Al), etc. Suspended in common liquids such as water and EG which recently were used in many fields of thermal engineering [2–5]. Therefore, extensive research has been done to improve heat transfer using active and passive methods [6–11]. In addition, a large number of studies devoted to using their base fluids. Hussien et al. [12] have reported the enhancement of forced convective heat transfer with different mass fractions of MWCNTs (0.075, 0.125 and 0.25 wt.%). Also, they observed an improvement in heat transfer coefficient with the increase in mass fraction of MWCNTs in the nanofluid reaching to 23.9% improvement at 0.25 wt.% MWCNTs/water at Re from 200 to 500. Kayhani et al. [13] studied experimentally an empirical analysis of pressure drop and forced convection turbulent flow heat transfer of Al₂O₃-water nanofluid with nanoparticles



of (40) nm size at (0.1, to 2) % volume concentrations inside a circular horizontal tube at constant heat flux in the tube wall. The experimental result exhibited the enhancement in Nusselt number 22% at Re of 13500 using 2% volume concentration of Al₂O₃-water nanofluid compared to distilled water. Carbon nanotubes have thermal conductivity reaching (2000- 3500) W/M. K [14]. Carbon nanotube exists as the single type particle such as single (SWNTs), multi-walled (MWCNTs) and doubles (DWCNTs) structures or like hybrid nanoparticles recently appeared [15]. Finally, in this research, we have used functionalized carbon nanotube type (Taunit M) in the base fluid of water to enhance heat transfer, and also it has created an experimental facility, which has high efficiency of heat transfer.

2. Materials and Methods

2.1. Nanofluids

Functionalized carbon nanotubes “Taunit M” was used in base fluid (water) for the enhancement of heat transfer. “Taunit M” carbon nanostructured materials manufactured at Nanotechnology Center (NanoTechCenterLtd) in Tambov, Russia [16]. The functionalized CNTs were prepared by using traditional method of chemical oxidation of CNT with sodium hypochlorite [17, 18]. Three concentrations of 0.01, 0.05, 0.1 vol.% have been used of functionalized carbon nanotubes “Taunit M as shown in figures 1 and 2.



Figure 1. FCNTs Taunit M nanofluids.



Figure 2. Samples of FCNTs.

2.2. The experimental facility

An experimental facility was designed and constructed to the measurement of heat transfer enhancement. The experimental facility, where the heat transfer enhancement was tested, consists of two principle circuits: the nanofluid circuit and the cooling circuit. Each one contains components and measuring devices. The principle components of this experimental facility are the test section, heat exchanger, nanofluid reservoir and centrifugal pump. Figure 3 shows the schematic diagram of the experimental facility.

The test section represents the main part of the test rig where the heat transfer coefficient, the pressure drop and characteristics of the nanofluid will be tested. The high thermal conductivity of the copper made it the first candidate to be the material of the test section pipe with the following details, as listed in table 1. The test section was prepared through the following steps.

- a) The nuts for temperature sensors (thermocouples) were fixed on the pipe's outer surface.
- b) The pipe was covered by an electrical insulator to prevent the electrical conduction between the heater and the test rig body.
- c) The electrical heater type FeCrAl (Iron – Chromium - Aluminum) alloy wire with 0.8 mm diameter, 2.8 Ω /m, 20 American Wire Gauge (AWG) [19] and 8.45 m length was used to generate a constant heat flux. With ceramic beads were wrapped around the pipe and connecting to the electric source with two ceramic joins.
- d) To minimize the heat losses and focus the heat on the pipe wall, a thermal-electrical resistance tape was used to wrap over the ceramic beads.
- e) To decrease the heat losses, 5 cm thickness of glass wool was used to cover the test section.

- f) Finally, an aluminum sleeve with 10 cm diameter was used to cover the test section.
- 2- The heat exchanger to reject the heat gained from the test section, shell and coil heat exchanger was manufactured and prepared for this task, with the following characteristics:
- The shell height is 0.7 m with 0.35 m diameter, manufactured from aluminum plate of 0.6 mm thickness.
 - The coil diameter is 0.27 m, manufactured from a copper pipe ($0.0127 \times 0.0071 \times 17$ m) diameter, thickness and length, respectively. The number of turns is 19 and the pitch between turns is 0.01 m. Two pipes of size (3/8") were welded on the coil in a diagonal shape to maintain the pitch distance and the coil straightening.
- 3- The nanofluid reservoir represents the feeding source of the nanofluid to the test rig. The diameter and height of this reservoir are 0.15 m and 0.6 m, respectively. The pump is connected to the lowest point in the reservoir. The desired flow rate of nanofluid that passes to the test section is secured by adjusting the valves and the excess nanofluid return to the reservoir through the bypass line. In addition, the centrifugal pump was selected for the test rig and its specifications to achieve the desired Reynold number.
- 4- The cooling cycle aims to reduce the temperature of the returned water from the heat exchanger and secure the required inlet temperature to the test section. It consisting of two centrifugal pumps in the cooling cycle, which are identical to the nanofluid's pump characteristics. In addition, the source tank is a cubic shape with 1 m³ capacity. In addition, the air cooler with 2500 m³/hr. capacity receives part of the hot water from the heat exchanger and reduces its temperature by passing through the wood fiber.
- 5- The air compressor is used to ensure that nanofluids are completely discharged from the working circuit after shutdown it.
- 6- The voltage stability is important for maintaining on the same work rhythm for the nanofluid pump; this means the same mass flow rate will pass through the test section.

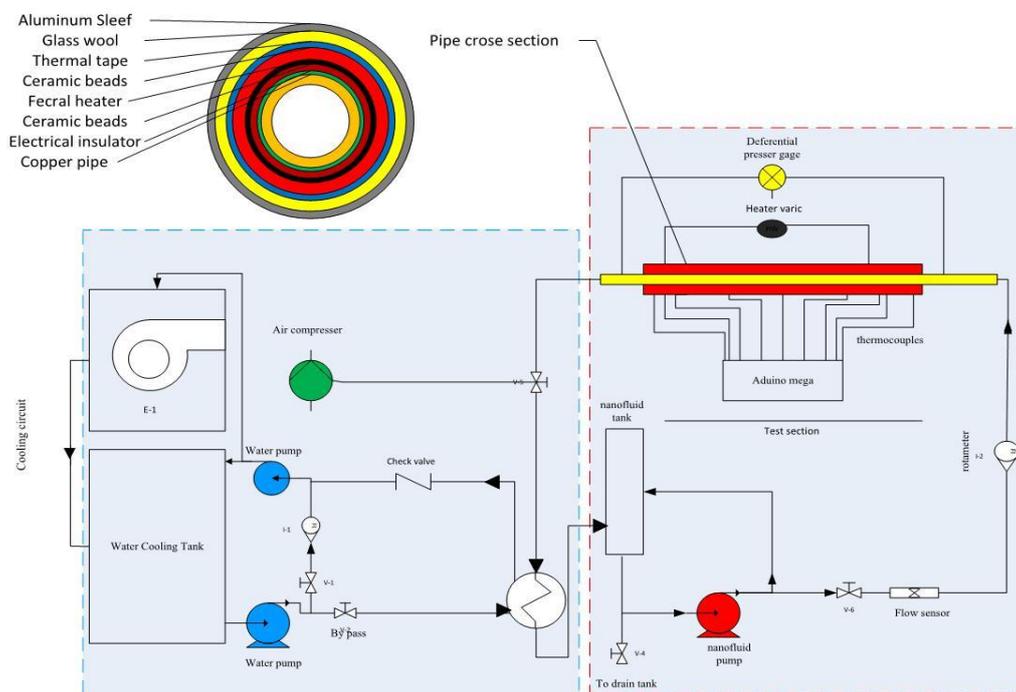


Figure 3. Scheme of the experimental setup.

2.3. Measuring Devices

1-Thermocouples to measure the variance of pipe surface and nanofluid temperatures along the test section, bolt and pressure spring thermocouples type K were used.

2-Three flow meters were used in the test rig, the first one is a flow sensor model YF-S201 working with Arduino technology at range (0 – 30 l/min) and located after the nanofluid pump discharge.

3-The pressure gauge (GRUNDFOS - Germany) to measure the pressure drop through the test section.

4-The Arduino technology was used with thermocouples, flow sensor and heater power in the test rig.

Table1. Copper pipe details.

Type	Length	Outer diameter	Inner diameter	Thickness
ACR-D	1000 mm	12.7 mm, 1/2"	10.7 mm	1.0 mm

In this study, the heater is generating a constant heat on the outer surface of the pipe:

$$Q_{heater} = I \times V \quad (1)$$

The generated heat is transferred through the pipe wall by conduction according to Fourier's law.

$$Q_{cond,pipe} = \dot{q} A_{s,out} = 2\pi\Delta x k \frac{[T_{s,out}(x) - T_{s,in}(x)]}{\ln(r_{out}/r_{in})} \quad (2)$$

Therefore, the heat flux on the outer surface of the pipe is given by:

$$\dot{q} = \frac{2k[T_{s,out}(x) - T_{s,in}(x)]}{D_o \ln(r_o/r_{in})} \quad (3)$$

The rate of heat transfer to the nanofluid is given by [20]:

$$Q_{nf} = \dot{q} A_{s,in} = \dot{m}_{nf} C p_{nf} (T_{nf,out} - T_{nf,in}) \quad (4)$$

where,

$A_{s,in} = \pi D_{in} L$, and rearranging the equation (4) gives:

$$\dot{q} = \frac{\dot{m}_{nf} C p_{nf}}{\pi D_{in} L} (T_{nf,out} - T_{nf,in}) \quad (5)$$

By applying the steady-state energy balance on a slice of the pipe (control volume) [21], the rate of heat that gained from the fluid is:

$$\dot{Q}_{in} - \dot{W}_{in} + \dot{m} h_{in} - \dot{m} h_e = 0 \quad (6)$$

After rearranging, the differential mean fluid temperature can be written as:

$$dT_m = \frac{\dot{q} p}{\dot{m} C p} dx \quad (7)$$

The local mean fluid temperature $T_m(x)$ can be determined by the integration of the equation (7) from $x = 0$ to x along the test section and assuming $T_{m,in}$ at $x=0$ is equal to $T_{nf,in}$

$$T_m(x) = T_{nf,in} + \frac{\dot{q} p}{\dot{m} C p} x \quad (8)$$

Substitution equation (5) into equation (8) will get the value of the local mean fluid temperature:

$$T_m(x) = T_{nf,in} + \frac{(T_{nf,out} - T_{nf,in})}{L} x \quad (9)$$

According to Newton's law of cooling:

$$Q_{nf} = h(x) A_{s,in} [T_{s,in}(x) - T_m(x)] \quad (10)$$

The heat flux will be:

$$\dot{q} = h(x) [T_{s,in}(x) - T_m(x)]. \quad (11)$$

Then, the local heat transfer coefficient is:

$$h(x) = \frac{\dot{q}}{[T_{s,in}(x) - T_m(x)]}. \quad (12)$$

The Nusselt number will be calculated locally at each section by the equation [22]:

$$Nu(x) = \frac{h(x) D_{in}}{k_{nf}}. \quad (13)$$

3. Results and discussion

The experimental results will be presented and discussed in detail the tests of convective heat transfer for the base fluid (water) as well as the nanofluids with particle loading of (0.01, 0.05, 1 and 0.1) vol.%. Experimental conditions are forced convection turbulent developing flow, with Reynolds number range of (5000, 7000, and 9000) and constant heat flux. To confirm the experimental test rig validity in convective heat transfer calculations as well as to provide a reference for comparison, the first test run was conducted on the distilled water only. The predicted Nusselt number calculated by Gnielinski equation (14) [23] for turbulent flow in the developing region and compared to present work versus Reynold number as shown in figure 4. The experimental behavior was conformable to the predicted values with deviation from 11% to 23% due to the experimental actual conditions.

$$u = \frac{\left(\frac{f}{8}\right) (Re - 1000) Pr}{1 + 12.7 \left(\frac{f}{8}\right)^{0.5} (Pr^{\frac{2}{3}} - 1)} \quad (14)$$

The surface temperature varied along the pipe length and increased as the axial distance increased due to the uniform heat flux effect on the surface. Figure 5 illustrates the surface temperature distribution along the test section for different Re numbers for the distilled water. The highest surface temperature appeared at the lowest value of Reynold number (Re = 5000). Also, this figure showed a decrement in the pipe temperature as the Re number increased due to the increase of water velocity.

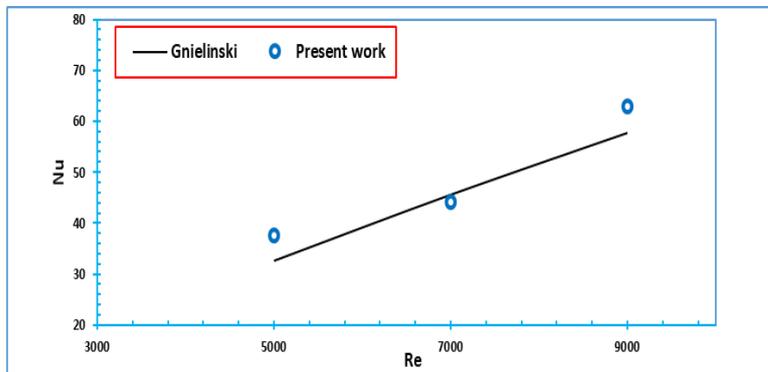


Figure 4. Experimental and theoretical Nusselt number for the distilled water.

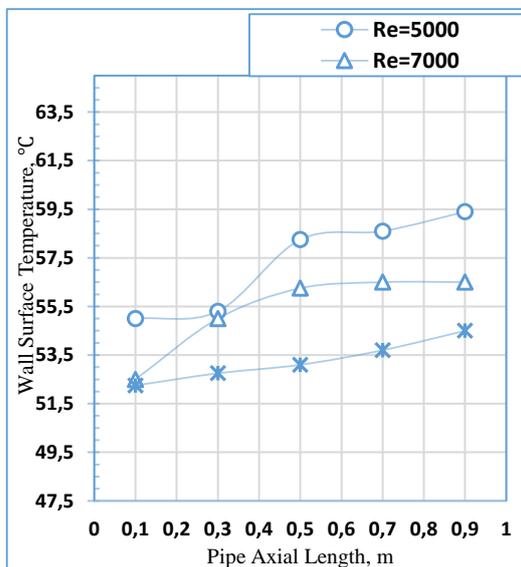


Figure 5. Surface temperature distribution along the pipe axial length for the distilled water at different Reynolds numbers.

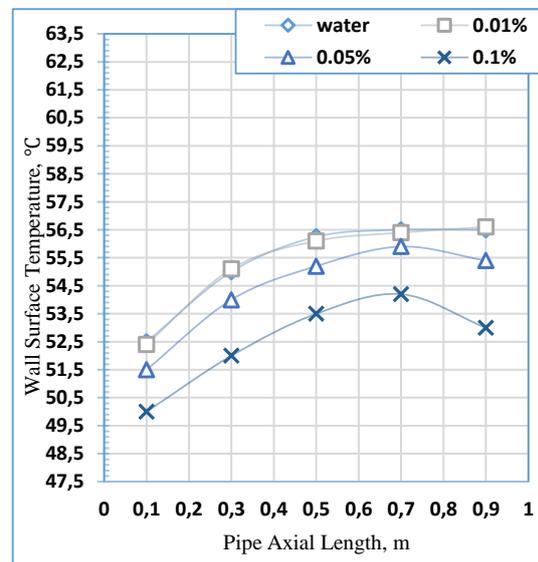


Figure 6. Surface temperature distribution along the pipe axial length for the distilled water and CNT (taunit m) nanofluid at different concentrations at Re =7000.

To make a reference for comparison among the experimental data, Re= 7000 was selected to clarify the nanofluid effect on the heat transfer performance. Figure (6) shows a decreasing in surface temperature with using nanofluid compared with water. The best performance was with 0.1% volume fraction. The average heat transfer coefficient versus Reynolds number is explained in figures (7). For figures 8 the enhancement in the average heat transfer coefficient reflected to the Nusselt number, where the maximum augmentation was 21% at 0.1 vol.% for particle loading, and 9000 Reynold number.

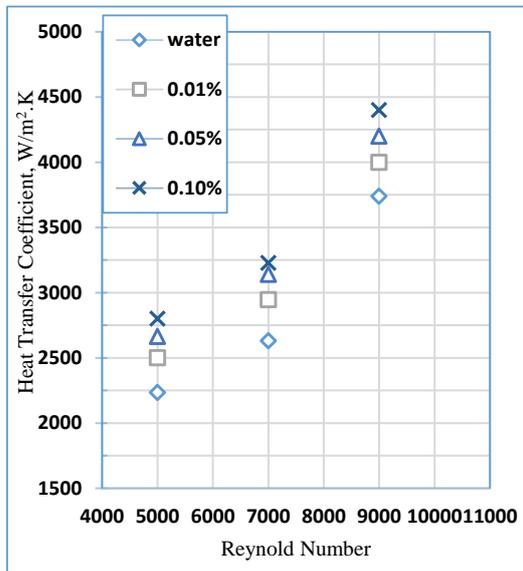


Figure 7. Average heat transfer coefficient for distilled water and CNT taunit nanofluid at different concentrations versus Reynold number.

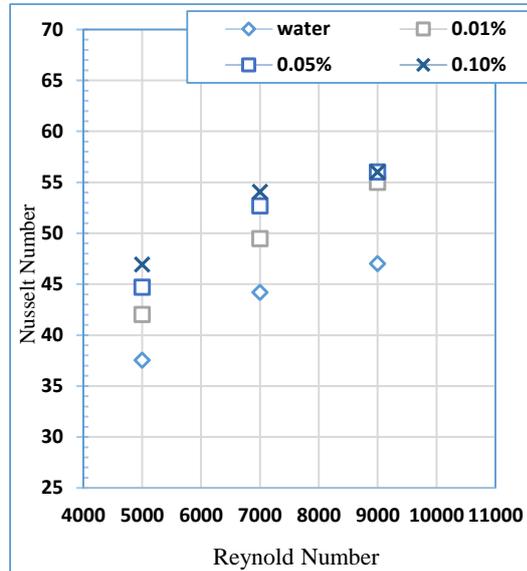


Figure 8. Average Nusselt number for distilled water and (CNT taunit m) nanofluid at different fractions versus Reynold number.

4. Conclusions

In this experimental study, adding the nanoparticles CNT type (taunit m) to the distilled water in small concentrations enhanced the heat transfer characteristic compared to distilled water, where the maximum enhancement in the Nusselt number reached to 21 % at 0.1 vol.% under Reynold 9000. As the volume fraction increased, the convective heat transfers augmented. The following suggestions are recommended for future work: studying the results of the present work theoretically and make a comparison between it and the experimental work, studying the heat transfer performance through the developing region under a turbulent flow regime and investigating the behavior of stable nanofluid under a laminar flow regime.

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