Experimental Study of Heat Transfer Improvement and Friction Loss of Nano Fluid Suspension Flow In Circular Pipe Heat Exchanger

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Abstract

This experiment focused on the study of convective heat transfer and friction loss in a circular flow passage for Graphene oxide-based nanofluids, which consist of Graphene oxide/DW in different wt.% concentrations. These Graphene oxide/DW-based nanofluids were prepared by using the facile two-step method, while the Graphene oxide nanoparticles were synthesized by the modified hummer method. Four different concentrations (0.025, 0.05, 0.075, and 0.1 wt. %) were produced by dispersing exfoliated Graphene oxide nanoparticles in distilled water under high probe sonication. The Graphene oxide/DW-based nanofluids flowing in a horizontal circular heat exchanger counter flow under turbulent flow conditions were investigated for heat transfer, Nusselt numbers, pressure drop, and friction loss studies. The constant heat flux and varying flow rate conditions were used to analyze the heat transfer improvement in a circular heat exchanger. The results showed that the convective heat transfer coefficient of the nanofluids was slightly higher than the base fluid at the same flow rate and the same inlet temperature. The heat transfer coefficient of the Graphene oxide/DW-based nanofluids increased by almost 9.8%, 15.2%, 18.9%, and 26% for concentrations of 0.025wt%, 0.05wt%, 0.075wt%, and 0.1wt%, respectively, when compared which was higher than the base fluid to distilled (DW). However, an increase in the concentration caused an increase in the viscosity of the nanofluid, which led to a slight increase in the friction factor. All the wt.% concentrations of Graphene oxide/DW-based nanofluids improved heat transfer properties as compared with the based fluid without solid graphene oxide nanoparticles.

Keywords: *Graphene Oxide-based Nanofluids; Heat transfer improvement; Pressure drop, Friction loss;*

1. Introduction

The cooling system is one of the most significant encounters of the many engineering sectors. A heat exchanger is used to transferring heat from one medium to another medium by using a different kind of fluids. For example, a swimming pool uses a boiler or solar-heated water to heat the swimming pool with the help of a heat exchanger. Heat is transferred by conduction through the exchanger materials which separate the mediums being used (Sankar, 2012). A shell and tube heat exchanger pass fluids through and over tubes, whereas an air-cooled heat exchanger passes cool air through a core of fins to cool a liquid. Water, ethylene glycol, etc. is used as a conventional heat exchanger fluid. Although various research and development are focusing on industrial heat transfer requirements, major improvements in cooling abilities have been lacking because conventional heat transfer fluids have poor heat transfer properties (Ahmed et al., 2021).

Researchers are trying out ways to improvise highly efficient fluid for the heat exchanger to be used in the future with better performance from the current fluids. Researchers have come out with metal oxide and carbon structured base nanofluids as a substitution fluid for heat transfer but the problem with metal oxide and carbon structured base Nanofluids was the sedimentation of particles in most of the cases (Ahmed et al., 2020; Kouloulias, 2016). The metal oxide and carbon structured base nanofluids failed to stabilize with base fluid for a long-term run. To overcome this problem surfactants and non-covalent functionalization methods are used to stable and homogeneous states.

At present, many researchers around the world testing surfactants and non-covalent functionalization methods to produce graphene oxide. Graphene has an excellent property in thermal, mechanical strength, electrical properties, and other properties that make graphene one of the useful materials for a wide range of applications (Kausar, 2018). Graphene is characterized as a carbon nanomaterial group, which means the main structure is made of carbon and difference based on the layer and shape of the material. Layers of graphene are arranged on top of each other to form graphite. The main idea of this thesis will focus on the new preparation methods of nanofluids and stability mechanisms, especially the new application trends for Nanofluids in addition to the heat transfer properties of nanofluids (Trisaksri & Wongwises, 2007; Ahmed et al., 2020).

The heat transfer improvement empowers the size of the heat exchanger to be decreased, upgrading the performance of the heat exchanger. The flow of genuine fluid exhibits viscous impacts inflow under turbulent flow conditions (Ahmed et al., 2020). The average heat transfer coefficient is an important factor evaluating convective heat loss or gains in thermodynamics, applied in Figureuring convection heat transfer among moving fluid and solid. To enhance the heat transfer coefficient on the internal surface and to obtain a large heat transfer area per unit volume, circular tube heat exchangers are usually utilized (Bisht, 2014). Approached in precisely forecasting the Nusselt number under completely developed flows and built a comparison on uniform wall temperature condition between circular and non-circular duct (Ahmed et al., 2020).

Conventional fluids such as oil, ethylene glycol, and also water have limited room in development as an energy-efficient medium of heat transfer as it is a low thermal conductivity source. With the aggressive progression of thermal engineering, the need to develop or identify a decisive heat transferring medium with optimal thermal conductivity for a better performance of heat transfer is crucial in recent years (Li, 2009) (Devendiran & Amirtham, 2016).

Solid nanoparticles (<100 nm) with high thermal conductivity dispersed into base fluids, called nanofluids, boosts thermal performance in a heat transfer system. The key reasons for the significant improvement are that the dispersed nanoparticles increase the heat capacity and surface area of the fluid, indirectly rises the thermal conductivity of the fluid. Due to the contact and impact among particles, fluid and flow passage surface intensifies, it flattens the temperature gradient of the fluid, escalating the mixing flux and turbulence of the fluid (Xuan & Li, 2000).

Anoop et al. (2009), investigated convective heat transfer in developing regions of pipe flow using alumina-water nanofluids concluded smaller nanoparticles show a higher heat transfer coefficient, increasing relative to increased particle concentration and flow rate. The heat transfer coefficient is the most important aspect in forced convection heating-cooling processes and it solely depends on variations such as particle size, particle shape, particle material, particle volume concentration, base fluid material temperature, and additives (Kakaç & Pramuanjaroenkij, 2009). Generally, the dispersion of nanoparticles (nanometer-scale solid particles) into base different conventional liquids are called nanofluids. There are two methods to produce nanofluids, there are a single-step method and a two-step method (Devendiran & Amirtham, 2016).

2. Objectives

The core intentions of the current study are given as follows.

1) To synthesize Graphene Oxide/DW-based nanofluids for the improvement of heat transfer, in which Graphene Oxide nanoparticles were produced by using the advanced modified Hummer method and then dispersed in distilled water by using a high probe sonication for the nanofluid preparation

2) To prepare different wt.% concentrations of Graphene oxide/DW-based nanofluids at varying (0.1, 0.075, 0.05, and 0.025) wt%. using 2-step nanofluids preparation method
3) To analyze the calculation of friction loss and pressure drop studies in the circular pipe heat exchanger
4) To study the dispersion/suspension and heat transfer characteristics of Graphene oxide/DW-based nanofluids at four different wt.% concentrations

3. Materials and Methods

3.1 Preparation of graphene oxide by Advance hummer method

In this research, the researchers aim to develop a method of Graphene Oxide to increase the stability in partial charges by using the hummer method. The main material used in this method was graphite powder, sulphuric acid, sodium nitrite, sodium hydroxide, hydrogen peroxide, potassium permanganate, and hydrochloric acid. This method has two stages as explained in detail below.

3.2 Synthesis of Graphene Oxide

Initially, 1.7 g of Graphite flakes and 0.7 g of sodium nitrite powder ($NaNO_3$) were added to 100 ml water. Further, 90 ml of sulphuric acid (H_2SO_4) was added into the mixture and kept in the beaker under continuous constant stirring for 30 minutes with an ice bath to maintain the surrounding temperature. In the next step, 1.7 g of potassium permanganate ($KMnO_4$) was added into the solution slowly while keeping the temperature less than 30°C to avoid overheating and explosion. The solution had been stirred for 8 hours at a controlled temperature of 30°C. The solution was diluted very slow by adding 100 ml of water and had been kept stirring for 2 hours at 30°C. Finally, the solution was treated with 40% hydrogen peroxide (H_2O_2) and had been continued stirring for 2 hours until the solution's color changed to bright yellow. The solution was washed with 10% aqueous hydrochloric acid, distilled water, and ethanol, respectively, a few times until forming like a gel substance (pH should be neutral). The gel substance was put in a vacuum oven and had been heated at 60°C for 6 hours. Finally, the Graphene oxide nanoparticles were obtained as in Figure 1.

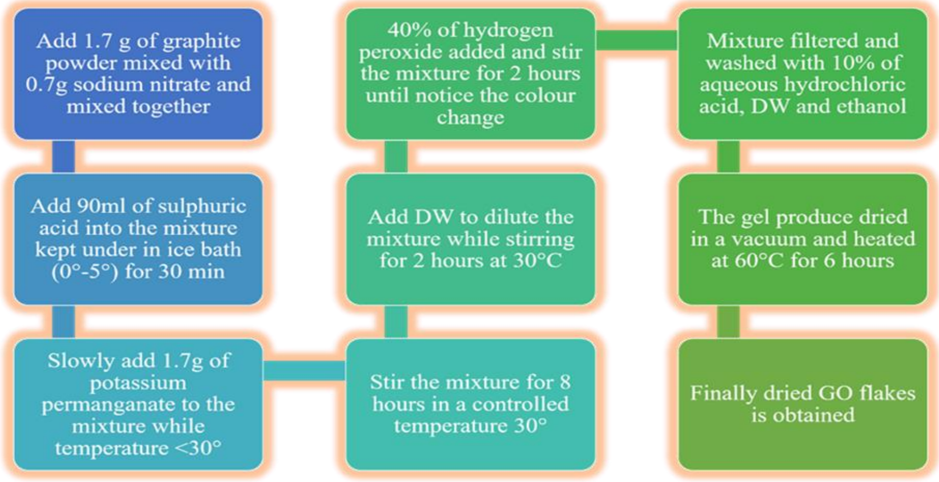


Figure 1 Single line flow of the synthesis of Graphene Oxide

3.3 Preparation of well-dispersed Graphene oxide/DW based nanofluids

From the earlier method, the researchers had to produce Graphene oxide with an advanced hummer method. Figure 2 presents the procedures to produce Graphene oxide/DW-based nanofluids, which are the simple steps that need to be done for the Graphene oxide/DW-based nanofluids preparation. Four varying (0.25, 0.05, 0.075, and 0.1) wt.% concentrations of Graphene oxide/DW-based nanofluids were prepared by using the ultrason chemical synthesis route. For this research, 7 liters of Graphene oxide/DW-based nanofluids were needed for each concentration; 0.025 wt. %, 0.05 wt. %, 0.075 wt. %, and 0.1 w.t%. Mixing of Graphene oxide/DW-based nanofluids refers to Table 1.

Table 1 Varying wt.% concentration of the Graphene oxide/DW based nanofluids

Concentration wt.%	GO Nanoparticles (g)	Distilled water (ml)
0.025	1.7 g	7000
0.05	3.5 g	7000
0.075	4.7 g	7000
0.1	7.0 g	7000

The amount of GO flakes based on the above table was added to distilled water, and an ultra-sonication process had been done for 2 hours to disperse and obtain the GO nanofluids as per needed concentration.

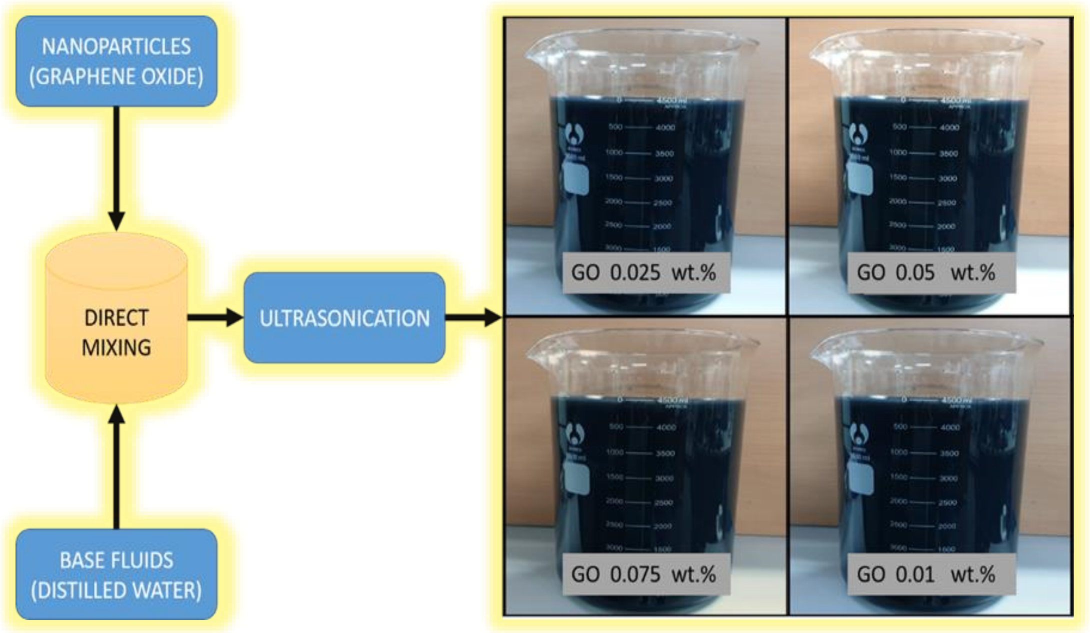


Figure 2 Typical Two-step preparation of GO/DW based nanofluids at varying wt.% concentrations

3.4 Experimental Setup

To evaluate the performance of heat transfer, the weight of each sample of nanofluids was mixed at 0.1 wt. %, 0.075 wt. %, 0.05 wt. %, and 0.025 wt. %. The experimental test rig in the setup at the advanced CFD laboratory at the University of Malaya was used to investigate hydrodynamic and convective heat exchange properties of GO in a circular test section. The rig parts are illustrated in Figure 3 below.

Figure 3 Complete heat transfer test rig for heat transfer measurement along with heat exchanger

Table 2 Different main parts of complete heat transfer test rig

No.	Parts
1	Storage Tank
2	Pump
3	Flow Meter
4	Stop Valve
5	Test Section
6	DP Meter
7	Data Logger
8	Chiller/Cooling Unit
9	Power panel
10	Control Panel

Before starting the experiment, the relevant valves, thermocouples, flow meter, and differential pressure transmitter were checked and calibrated. The surface temperature of the pipe measured at the depth of the wall thickness was transferred to the internal surface temperature of the test pipe by using the Wilson plot (Fernández-Seara, 2007). Thermophysical properties of DW and Graphene oxide/DW-based nanofluids were measured to calculate the pressure drop (Pa m^{-1}), Nusselt number (Nu), heat transfer coefficient (h), and friction loss (f). Reynolds (Re) number of distilled water and Nanofluids with different concentrations and flow had also been considered. The experiment was conducted on the horizontal circular cross-section on the straight tube. The test section was made of a stainless-steel tube with a length of 1.2 m, and the widths of the tube were 10 mm internal diameter and 12 mm external diameter that was wrapped with glass wool to create the insulation layer. The test section was wrapped by a flat wire heating element, which the variable transformer controlled the power of the heating element. At the inlet and outlet of the test, a section thermocouple was installed to measure the temperature at each point, respectively. At the surface of the tube, five K-type thermocouples (accuracy ± 0.1°C) were installed at 0.3 m from the entering of the nanofluids sample, and the distance in between each thermocouple was 0.2 m. The tube was wrapped uniformly by two thick thermal insulation layers (glass wool) to ensure the readings taken were valid and the heat loss from the tube line was reduced.

4. Result and discussion

4.1. Analysis of average heat transfer coefficient and Nusselt numbers by using graphene oxide/DW-based nanofluids in a circular pipe heat exchanger

As per our methodology, the researchers had done a sequence of experiments using Graphene oxide/DW nanofluids and distilled water at constant heat flux boundary conditions in a circular tube. The researchers determined the Nusselt numbers based on our experimental data collected. Hence, our experimental set-up can be employed to calculate the heat transfer properties of the Graphene oxide/DW nanofluids and distilled water. To study the convective heat transfer coefficient and Nusselt number of the Graphene oxide/DW nanofluids and distilled water at varying wt.% concentrations (0.025, 0.05, 0.075, and 0.1). With obtained results from the experiment, the researchers calculated the heat transfer coefficient of Graphene oxide/DW and distilled water by using numerical calculations. The researchers present the results of the heat transfer coefficient with the function of the Reynolds number in Figure 4a. It can be seen that there is an increase in the convective heat transfer coefficient when the Reynolds number increases at varying wt.% concentrations of the Graphene oxide/DW nanofluids and distilled water as well. However, the highest concentration of 0.1 wt.% gives more heat transfer when compared with other concentrations and base fluid.

Furthermore, an obvious effect on the convection heat transfer coefficient can be seen when the concentration of Graphene oxide nanoparticles increases. These characteristics affect the decreased thermal boundary layer thickness as well as the increased thermal conductivity in the presence of Graphene oxide/DW nanofluids. Based on the data in Figure 4a, the researchers identified that the convection heat transfer coefficient of the Graphene oxide/DW nanofluids increased by almost 9.8%, 15.2%, 18.9%, and 26% for concentrations of 0.025wt%, 0.05wt%, 0.075wt%, and 0.1wt%, respectively, when compared with the distilled water. These results were obtained by using a constant heat flux of 21,500 W/m^2. The mathematical equation was used to calculate the average Nusselt number by inserting the average convective heat transfer coefficient value for Graphene oxide/DW nanofluids and distilled water. Figure 4b represents the results for the average Nusselt number vs. Reynolds number. Based on the graph in Figure 4.2, the researchers can see the increase in the Nusselt number when increasing the Reynolds number. The researchers identified that the Nusselt number of the Graphene oxide/DW-based nanofluids increased by almost 9.6%, 14.9%, 18.6%, and 23.7% for concentrations of 0.025wt%, 0.05wt%, 0.075wt%, and 0.1wt%, respectively, when compared with the base fluid.

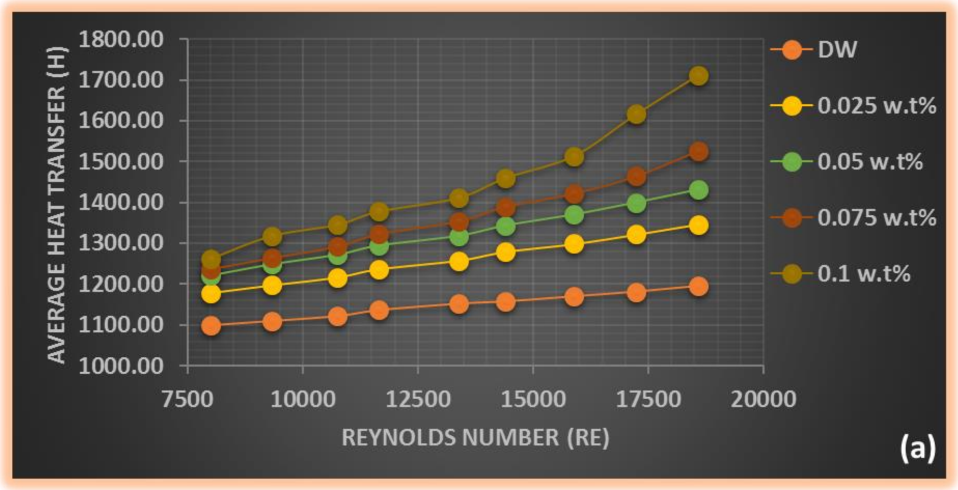


Figure 4 Average heat transfer and Nusselt numbers growth of Graphene oxide/DW-based nanofluids

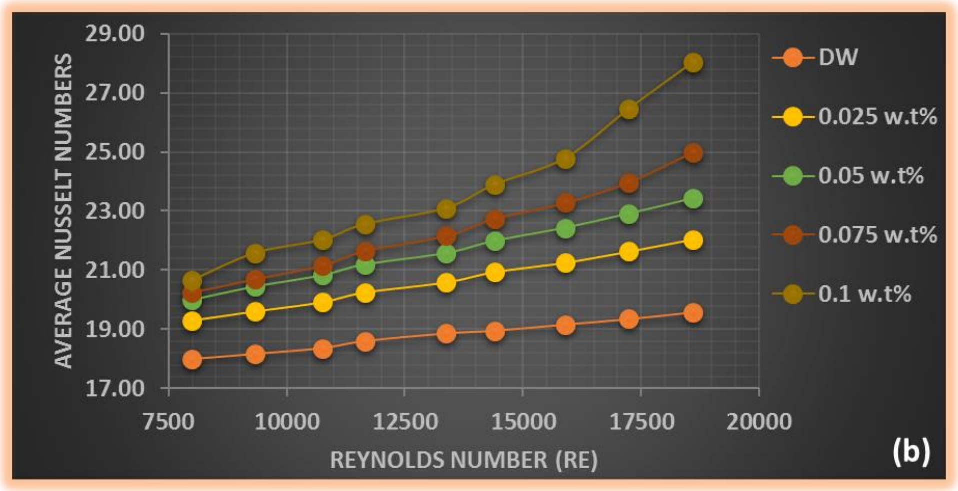


Figure 4 (cont.) Average heat transfer and Nusselt numbers growth of Graphene oxide/DW-based nanofluids

4.2. Improvement in Local heat transfer coefficient (h)

The local heat transfer measurements (h1, h2, h3, h4, and h5) were taken on each thermocouple (T1, T2, T3, T4, and T5) of the circular pipe heat exchanger. The constant heat flux and variable flow rate conditions were considered throughout the experiment. Nine varying flow rates were used during the test running and different Reynolds numbers from (7996-18589) were calculated. Figures 5a-d are showing that as the Reynolds number increases, the local heat transfer increases, in which the maximum heat transfer was noticed at h1, which is nearest to the inlet point. Similarly, all the wt.% concentrations of Graphene oxide/DW-based nanofluids give escalating heat transfer as compared with the base fluid. At 0.025 wt.% Graphene oxide/DW-based nanofluid, the maximum heat transfer was about 1875 W/m.K, while at 0.05 wt.% the heat transfer was 1975 W/m.K. Similarly, at 0.075 wt.%, the maximum enhancement was recorded at about 2100 W/m.K, and finally, at 0.1 wt.%, the supreme heat transfer was noticed at about 2855 W/m.K. All wt.% concentrations of Graphene oxide/DW-based nanofluids showed improved heat transfer compared with the base fluid. This improvement may be credited to the maximum presence of Graphene oxide nanoparticles, their surface area, and suspension in the base fluid.

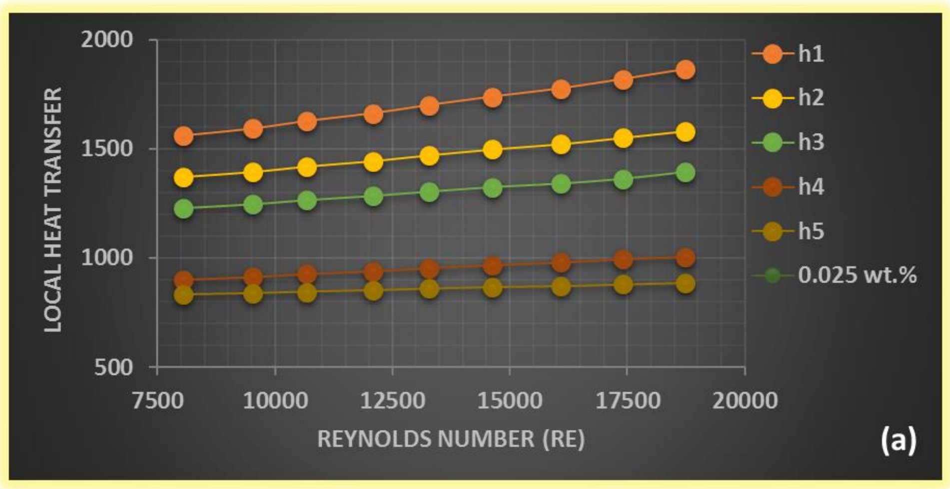
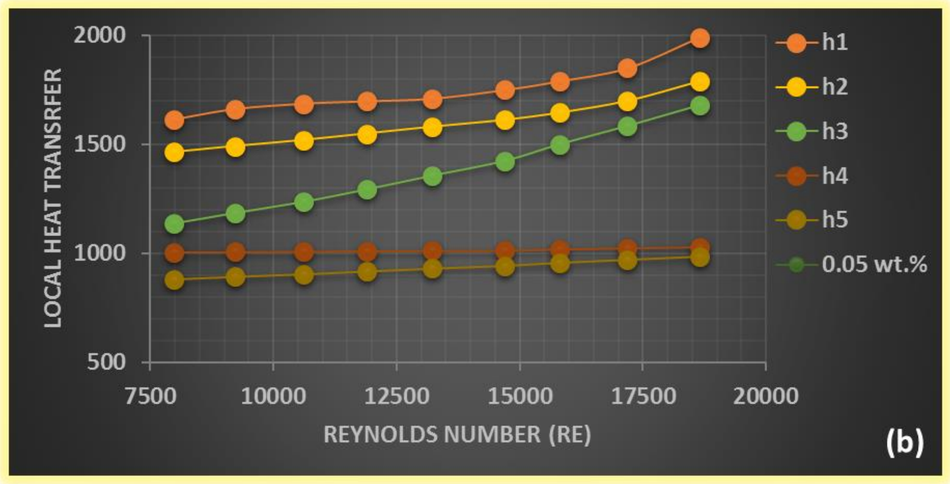
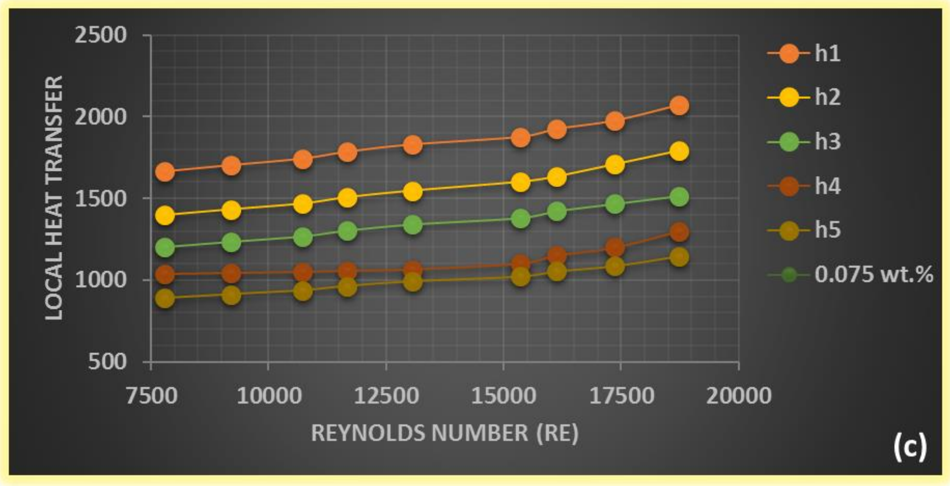


Figure 5a-d Improvement in local heat transfer vs Reynolds numbers of Graphene oxide/DW-based nanofluids





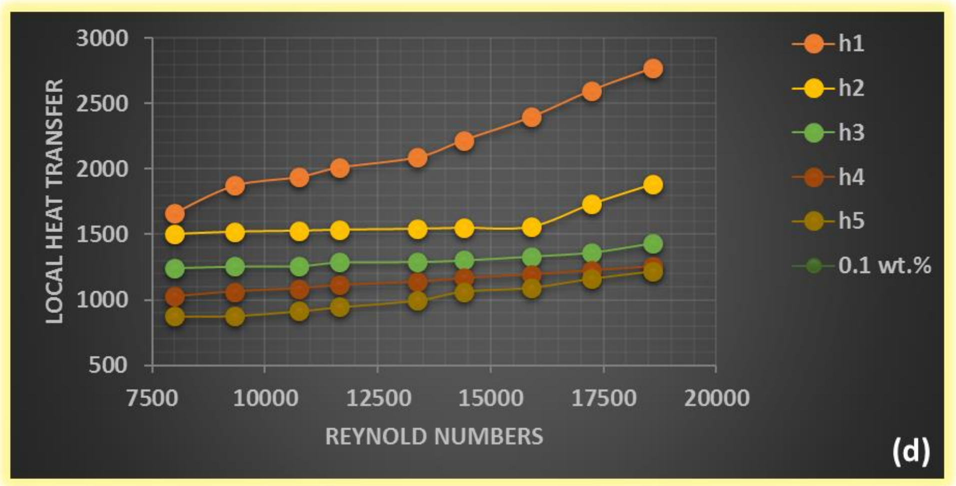


Figure 5a-d (cont.) Improvement in local heat transfer vs Reynolds numbers of Graphene oxide/DW-based nanofluids

4.3. Pressure drop and Friction loss Analysis of Graphene oxide/DW nanofluids in the circular heat exchanger

Based on the results obtained as shown in Figure 6a on differential pressure versus Reynolds number, when the flow rate increases, the pressure drop across the test section of circular increases gradually. By comparing the Graphene oxide/DW nanofluids with the base fluid, Graphene oxide/DW had a slightly higher pressure drop across the test section due to their increased viscosity. The increase in the pressure drop was due to the viscosity, and the density of the fluid was slightly higher than the base fluid. The researchers identified that the differential pressure of the Graphene oxide/DW nanofluids increased by almost 3.3 %, 8.8 %, 13.7 %, and 19.0 % for concentrations of 0.025wt%, 0.05wt%, 0.075wt%, and 0.1wt%, respectively, in average differential pressure when compared with the distilled water.

To determine the friction factor, the Reynolds number was calculated from the collected data. Further, the internal friction was analyzed when the nanofluid run inside the test section. Figure 6b shows the friction loss for both DW and the Graphene oxide/DW-based nanofluids, where the distilled water had a slightly lower friction factor compared with the Graphene oxide/DW nanofluids. The increase in friction loss was due to the increase in the wt.% concentration of Graphene oxide nanoparticles in the base fluid. The friction loss for the Graphene oxide/DW-based nanofluids increased by almost 1.03%, 1.51%, 2.20%, and 2.64% for concentrations of 0.025wt%, 0.05wt%, 0.075wt%, and 0.1wt%, respectively.

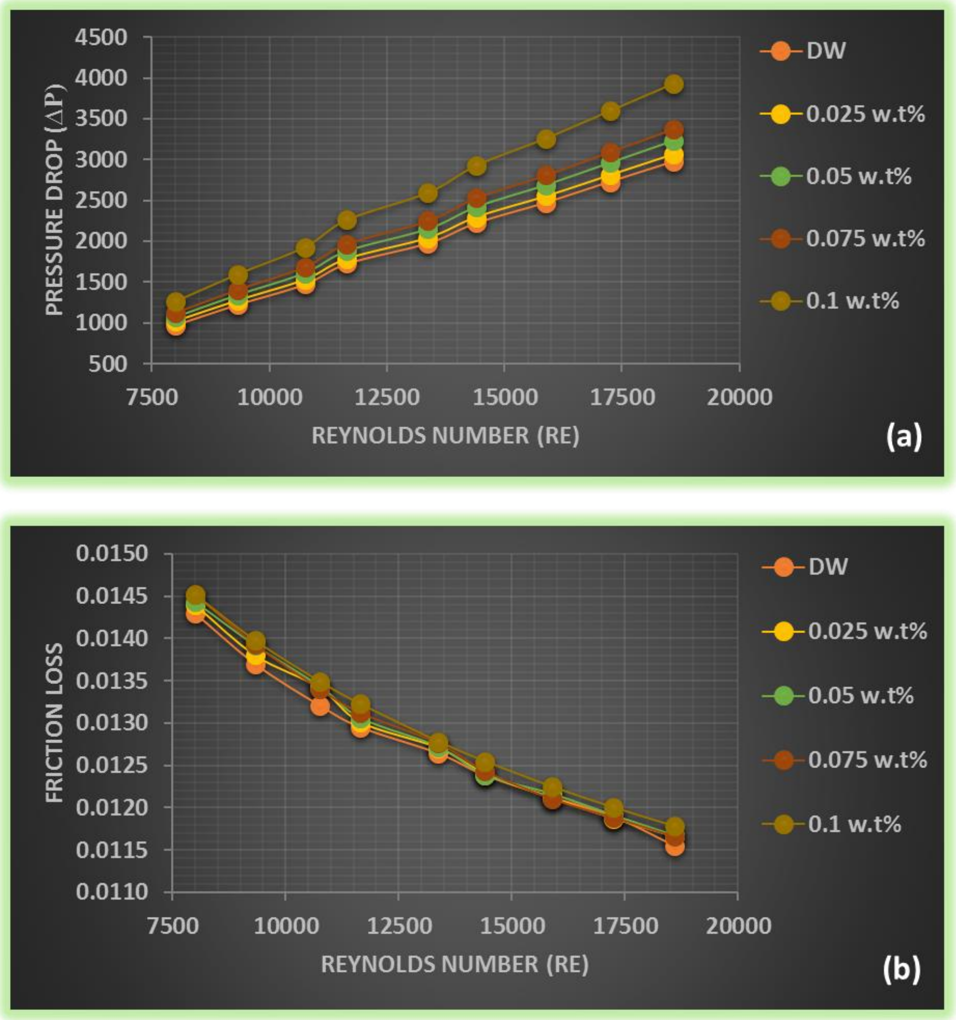


Figure 6 a) Pressure drop losses versus Reynolds numbers and b) friction loss measurement in the circular tube heat exchanger for Graphene oxide/DW nanofluids

6. Conclusion

In this study, the Graphene oxide nanoparticles were synthesized through the advance/modified hummer method with improved heat transfer and hydrodynamic properties. Further, the preparation of the Graphene oxide/DW-based nanofluids at four varying wt.% concentrations (0.025, 0.05, 0.075, and 0.1) was done by using a 2-step ultra sonochemical procedure. The Graphen oxide/DW-based nanofluids at varying wt.% concentrations and the base fluid were tested for heat transfer improvement on a complete heat transfer test rig, where the average heat transfer coefficient, average Nusselt numbers, local heat transfer coefficient (h), the pressure drop across the pipe, and friction loss were analyzed. Based on the experimental analysis, the following important finding has been concluded.

- There was an obvious increase in the convective heat transfer coefficient and Nusselt number for the Graphene oxide/DW nanofluid at the highest concentration of 0.1 wt.% Graphen oxide/DW-based nanofluids with the maximum Reynolds numbers, which is approximately 26.0 % more than the base fluid.
- All the wt.% concentrations of the Graphene oxide/DW-based nanofluids give an improvement in the heat transfer properties when compared with the base fluid.

- Based on the average and local heat transfer improvements, all wt.% concentrations offers improved Nusselt numbers with an increase in Reynolds numbers, which is higher than the base fluid.
- More importantly, there was a slight increase in the corresponding friction loss at the lowest value of Reynolds numbers, which is about 2.46 % at the concentration of 0.1 wt.% Graphene oxide/DW-based nanofluids. As the Reynolds number increases, the friction starts to reduce, which is a common phenomenon.
- The maximum pressure drop across the circular pipe heat exchanger recorded at 0.1 wt.% Graphene oxide/DW-based nanofluids was 4100 Pa for the maximum value of the Reynolds number. This increase in pressure drop was due to the maximum presence of the Graphene oxide nanoparticles in the base fluid, which increased its viscosity and the system needed more pumping power.
- In summary, the researchers conclude that the Graphene oxide/DW-based nanofluid has a high potential to use as an alternative heat transfer fluid in various heat transfer systems.

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