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Convective heat transfer enhancement of graphene nanofluids in shell and tube heat exchanger

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ABSTRACT

Current research suggests a promising future for graphene nanofluids. The main focus of this research is on developing higher convective heat transfer behavior of graphene nanofluids through the shell and tube heat exchanger under laminar flow. Graphene nano sheets were prepared by CVD method and their morphology was investigated by SEM and Raman spectroscopy. The convective heat transfer coefficients of graphene nanofluids based on water in the entrance region and under laminar conditions have been measured. Also the effect of temperature and concentration on convective heat transfer coefficients of graphene nanofluids has been discussed. According to the results, adding 0.075% of graphene to the base fluid contributes to an improvement of thermal conductivity up to 31.83% at saturation concentration of graphene and an enhancement in heat transfer coefficient which depends on the flow conditions. The convective heat transfer coefficient of graphene nanofluids at 38 °C enhanced up to 35.6% at a concentration of 0.1 wt% compared with pure water.

1. Introduction

Nanofluids are suspensions that can be obtained by dispersing different nanoparticles in host fluids with the aim of enhanced thermal properties [1]. Over the past few years, it has been shown that nanofluids are able to remarkably improve the thermal conductivity, stability and heat transfer coefficient and reduce the consumed power and the costs [2–5]. These advantages made a growing tendency in the use of nanofluids in different types of heat exchangers, due to the optimized energy consumption. Hence, discovering suitable nanofluids with improved heat transfer properties and high thermal conductivity became a serious challenge. More specifically graphene water-based nanofluids reveal great improvements, which is owing to the high thermal conductivity of graphene [6]. The experimental studies have reported significant enhancement on the thermal conductivity and heat transfer coefficient of nanofluids. Many studies evaluated the convective heat transfer of nanofluids [7–10]. For example it has been shown that alumina–water nanofluid at 6 vol% can increase the heat transfer coefficient in the entrance and fully developed regions by 17% and 27%, respectively, when compared with pure water. The heat transfer coefficient of zirconia–water nanofluid increases by approximately 2% in the entrance region and 3% in the fully developed region at 1.32 vol% [11]. For nanofluids containing 0.5 wt% CNTs, the maximum enhancement is over 350% at Re = 800, and the maximum enhancement occurs at an axial distance of approximately 110 times of tube diameter [12]. In this paper, graphene nano sheets were synthesized by CVD method and then they were used as a nanofluid for enhancement of heat transfer coefficient in shell and tube heat exchanger. The laminar convective heat transfer behavior of graphene nanofluids through a straight tube was experimentally investigated. Furthermore, it was attempted to discover the effect of different parameters such as temperature and graphene concentration on convective heat transfer coefficients of graphene nanofluid.

2. Experimental

2.1. Preparation and Characterization of graphene nanofluid

To prepare graphene aqueous fluid, deionized water was used as the base fluid and graphene sheets were used as the additive. These nano-sheets were grown by using catalytic decomposition (CVD) method over copper foil (with thickness of 30 m) which

Abbreviations: CVD, chemical vapor deposition; CNT, carbon nanotube; SCCM, standard cubic centimeters per minute; SEM, scanning electron microscope; KPS, potassium persulfate; Nu, nusselt number; H, heat transfer coefficient; L, Length; Re, Reynolds; μ, Viscosity; ρ, Density; cp, specific heat; KRG, alkaline oxide of graphene; h_x, local heat transfer coefficient; D_0, outer tube diameter.

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was purchased from Aldrich. This method involves methane and hydrogen gasses (from an Iranian gas corporation), with a purification of 99.999%, under vacuum condition of 10 mTorr. The furnace was heated with a 3 sccm flow of hydrogen gas up to 1050 °C. After 40 min of heating, a flow of 35 sccm methane gas was introduced into the system for a grow time of 15 min. A quick cooling procedure was performed after growth. Afterwards, copper particles were removed by using purification treatments [13]. Fig. 1 represents the SEM image of purified graphene.

As it is obvious in Fig. 1, a large area can be identified on Graphene sheets. Also it can be observed that the structure of CVD-grown Graphene is in the nano range, at least in one dimension. In order to obtain hydrophilic structure of Graphene in water, an alkaline oxidation media with KPS was applied [13]. Raman spectra were excited by a 532 nm YAG-YAG laser at a resolution of 2 cm^{-1} between 100 and 4000 cm^{-1}. A small amount of CVD Graphene was placed on a polished metal surface on the stage of Raman spectra. The Raman spectrum of CVD Graphene is shown in Fig. 2 and it displays all common features of graphene previously reported in the literature [14].

The typical features for carbon in Raman spectra are the *G* line around 1582 cm^{-1} and the *D* line around 1350 cm^{-1}. The *G* line is usually assigned to the E2g phonon of *C* sp2 atoms, due to crystalline structure, while the *D* line is a breathing mode of *k*-point phonons of A1g symmetry due to amorphous carbon content [15,16]. As shows in Fig. 2, the Raman spectrum of the pristine graphene displays a strong G line at 1592 cm^{-1}, a weak *D* line at 1361 cm^{-1}. The intensity of the *D* and *G* band were 455 and 1853 respectively. These values are attributed to the structure of pure graphene decreased with sp2 domains [15].

For making the nanofluid samples, first the suspensions with concentrations of 0.05, 0.075 and 0.1 wt% of alkaline graphene oxide in water were prepared. Then they were sonicated for 15 min at room temperature and were named as KRG-2, KRG-3 and KRG-4, respectively.

2.2. Experimental setup and calibration

The experimental setup consists of a pump, a tank and a cooling system and the test section which is composed of a horizontal circular copper tube of 1 m length with an inner diameter/outside-diameter of 1.07/1.30 cm. Ni–Cr heater wire with resistance of 2.3 Ω/m with 7.5 m length was enfolded around the copper tube to provide a constant heat flux all along the test section. The heater wire was connected to an AC power supply which was tunable. There was a rock wool thermal insulating layer by about 150 mm thick surrounding the heater in order to acquire uniform heat flux.

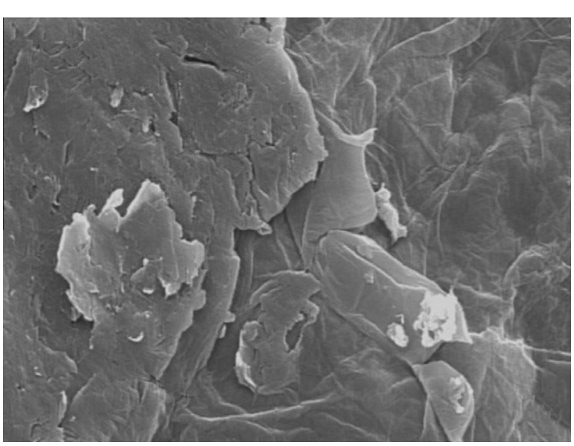

Fig. 1. SEM image of graphene.

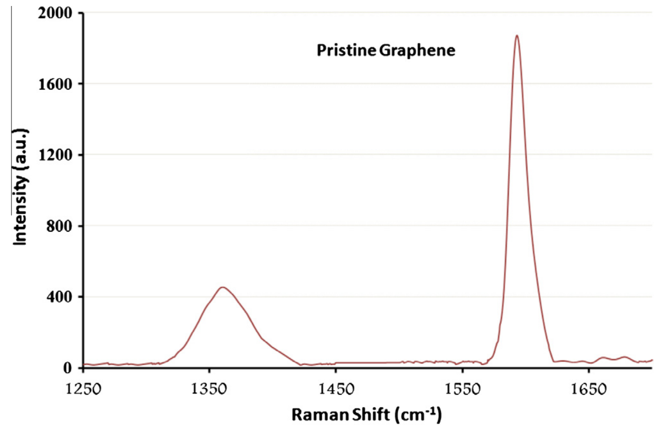

Fig. 2. Raman spectrum of CVD graphene.

5(K-type) thermocouples were placed in equivalent interval on the copper tube in order to measure wall temperatures. Furthermore, two thermocouples were installed into the flow at two extremes of the heat exchanger. The schematic of shell & tube heat exchanger has been represented in Fig. 3.

In order to obtain accurate experimental measurements, initially the calibration of system was performed. For calibration, some experiments were executed for DI water and the experimental results of convective heat transfer coefficient (*h*) and Nusselt number (Nu) were compared with standard correlations. Then the error of the system was measured to ensure the accuracy of system.

To establish a laminar flow, volumetric flow rate of 0.8 lit/min was fed to the system. Then a power supply of 25 V was applied producing a heat flow equal to q_1 = V.I = 227.7 W on the outer surface of copper tube. Temperature of inlet (T_{in}) and outlet (T_{out}) were 25.8 and 29.7 °C respectively. Thermo physical properties of water in mean temperature of water calculated at $\bar{T}_f = (T_{in} + T_{out})/2 = 27.75°C$ have been reported from standard references in Table 1 [17].

Moreover the mass flow was calculated as $\dot{m} = \rho = \dot{Q} = 13.29\ g/s$, the velocity was defined as $u = \dot{Q}/(\pi D_i^2/4) = 15.5\ m/s)$ and the heat transfer rate from tube wall to the fluid was obtained by$q_2 = \dot{m} \cdot C_p(T_{out} - T_{in})$ correlation as 216.6 W. There was a negligible difference between q_1 and q_2

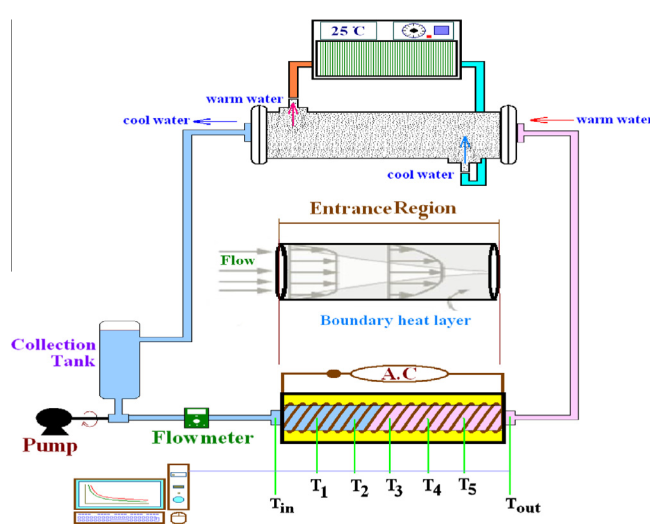

Fig. 3. Schematic of the experimental set up.