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Graphene nanoplatelets–silver hybrid nanofluids for enhanced heat transfer

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ABSTRACT

In the present experimental work, a new synthesis method is introduced for decoration of silver on the functionalized graphene nanoplatelets (GNP–Ag) and preparation of nanofluids is reported. The thermo-physical properties, heat transfer performance and friction factor for fully developed turbulent flow of GNP–Ag/water nanofluids flowing through a circular tube at a constant heat flux were investigated. GNP–Ag uniform nanocomposite was produced from a simple chemical reaction procedure, which includes acid treatment for functionalization of GNP. The surface characterization was performed by various techniques such as XRD, FESEM, TEM and Raman. The GNP–Ag nanofluids were prepared by dispersing the nanocomposite in distilled water without the assistance of a surfactant and/or ultrasonication. The prepared nanofluids were found to be stable and no sedimentation was observed for a long time. The experimental data for GNP–Ag nanofluids were shown improvements of effective thermal conductivity and heat transfer efficiency in comparison with the corresponding to the base-fluid. The amount of enhancement was a function of temperature and weight concentration of nanoparticles. Maximum enhancement of Nusselt number was 32.7% with a penalty of 1.08 times increase in the friction factor for the weight concentration of 0.1% at a Reynolds number of 17,500 compared to distilled water. Improved empirical correlations were proposed based on the experimental data for evaluation of Nusselt number and friction factor.

1. Introduction

Water, engine oil and ethylene glycol are commonly used as working fluids for transfer of heat in many industrial equipment such as heat exchangers, cooling devices and solar collectors. Small improvement in efficiency of heat exchanger equipment could lead to huge saving in initial and operational costs. One way to achieve this aim is to enhance the effective thermal conductivity of fluids that transfer the heat. Since the thermal conductivity of most liquids is low, there has been interest to use suspended solid particles to enhance the thermal conductivity of the base-fluid. Dispersion of micrometer or even millimeter particles in base-fluid was used earlier by researchers. However these earlier attempts have faced obstacles such as, increasing in pressure drop, sedimentation of particles and erosion of equipment. Choi and his co-worker in 1995 have found a new class of fluids with suspension of nanoparticles that is called “nanofluid”. Investigation showed that nanoparticles have the ability to improve the effective thermal conductivity of base fluid and are useful for different industrial applications [1–3].

In the past decade, researchers examined many kinds of nanomaterials for preparing nanofluids. Al_2O_3,CuO, ZnO, silver and zirconia were typically used in many nanofluids compared to other kinds of metal oxide nanomaterials [4–7]. Carbon based materials such as CNT [8,9], GO [10] and graphene were also examined experimentally by a number of researcher [11–16]. Nanofluids have attracted researchers since the material in the nanometer size have unique physical and chemical properties. In particular, many nanofluids have shown enhanced thermal conductivity, which makes them suitable for use as working fluids. Experimental

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Nomenclature

A	area, m^2
C_p	specific heat, J/kg K
D	inner diameter of the tube, m
f	friction factor
h	heat transfer coefficient, W/m^2 K
I	current, Amp
k	thermal conductivity, W/m K
l	length of the tube, m
$\dot{m}$	mass flow rate, kg/s
Nu	Nusselt number,
P	power, Watts
Pr	Prandtl number, μC/k
Q	heat flow, Watts
q	heat flux, W/m^2
Re	Reynolds number
T	temperature, °C
V	voltage, Volts
v	velocity, m/s
Greek symbols	
Δp	pressure drop
φ	weight concentration of nanoparticles, %
μ	viscosity, kg/m^2 s
ρ	density, kg/m^3
Subscripts	
b	bulk
Exp	experimental
i	inlet
o	outlet
Reg	regression
w	wall

studies also revealed that adding nanoparticles base fluid not only enhances thermal conductivity but also augments convective heat transfer compared to pure base fluids.

In the recent years, significant investigations on the use of carbon-based nanomaterials such as, single-wall carbon nanotube, multi-wall carbon nanotube, graphene oxide and graphene nanoplatelets (GNP) to make nanofluids were reported in the literature [17–20]. New research indicates that graphene nanofluids could provide higher thermal conductivity enhancement in comparison to other tested nanofluids. Graphene particles have better thermal conductivity and also higher mechanical strength, and electrical conductivity. Favorable thermo-physical properties of graphene has made it an excellent candidate for use in nanofluids [21]. In addition, synthesizing graphene nano-particles is relatively easy and cost effective. Small variation of properties of graphene has been reported due to different methods used to manufacture one layer or multi-layer graphene such as, exfoliation of graphene oxide layer, deposition with chemical vapor and mechanical cleavage, etc. [21–24]. Experimental investigation has revealed that the thermal conductivity and heat transfer properties of one layer graphene are higher than CNT. Two-dimensional honey comb lattice graphene with more than 10 layers called Graphene nanoplatelets (GNP). Dispersion of graphene with good stability is one of the big issues must be solved. So by using functionalization method (acid treat and amino function), proper ultrasonic and solvent it could be able to prepare stable dispersed graphene based nanofluids [25,26].

Majority of earlier investigation on nanofluid regarding thermo-physical properties and heat transfer coefficient was done on single nanoparticles; based on them, graphene based nanofluids provided the best heat transfer coefficient. Synthesis of nanocomposite and preparation of nanofluid based on nanocomposite are very new and interesting topic for researcher [27,28]. Hybrid nanofluid of Al_2O_3–Cu has experimentally investigated by Suresh et al. [29]. They reported that about 14% enhancement in Nusselt number for laminar flow was achieved in comparison with pure water. Sunder et al. [30] synthesized MWCNT-Fe_3O_4 nanocomposite and prepared hybrid nanofluid and achieved 31% improvement in Nusselt number at 0.3% volume concentration and at Reynolds number of 22,000. Tessy et al. [31] synthesized and prepared hybrid CuO-HEG nanofluid and obtained 28% enhancement in thermal conductivity for 0.05% volume concentration of functionalized graphene without any surfactant.

In the present work, GNP–Ag nanocomposite powder is synthesized by chemical reaction process. GNP was functionalized by acid treatment method and further decorated with Silver. After that GNP–Ag/water hybrid nanofluids were made by dispersing the nanocomposite material in distilled water. The purpose of present study is to measure experimentally the thermal conductivity, viscosity, Nusselt number and heat transfer coefficient in turbulent flow of GNP–Ag/Water nanofluids in a pipe at a constant heat flux. To the best of authors literature, has been no reported investigation on the preparation, thermal conductivity and Nusselt number of GNP/Ag dispersed nanofluids.

2. Materials and methods

2.1. Synthesis of GNP–Ag nanocomposite

GNP with purity ~99.5%, maximum particle diameter of 2 μm and specific surface area 500 m^2/g were purchased from, XG Sciences, Lansing, MI, USA. Rest of the chemicals and materials such as Silver, HNO_3 (nitric acid), H_2SO_4 (sulphuric acid) and NaOH (sodium hydroxide) were procured from Sigma–Aldrich Co., Selangor, Malaysia.

Since graphene nanoplatelets is naturally hydrophobic and it cannot be dispersed in any solvent which is polar like distilled water. Functionalization by acid treatment is a suitable way to make GNP hydrophilic. This functionalization process helps to introduce functional groups such as carboxyl and hydroxyl groups on the surface of GNP. Acid treatment process was conducted by dispersing GNP in a 1:3 ratio of HNO_3 and H_2SO_4 solution (strong acid medium) for 3 h under bath-ultrasonication. After 3 h, GNP were washed several times by DI water and then dried in an oven at the temperature of 70 °C for more than 24 h. Later the functionalized GNP were decorated with 17% Ag by a chemical reaction method. The brief procedure of synthesis is stated for reference. The solution of ammonia-silver was prepared by adding drop wise ammonia (1 wt%) to 0.01 L silver nitrate solution (0.05 M) until fully reacted and silver color disappeared. The Ag $(NH_3)_2OH$ solution (0.04 M) was mixed with 120 ml functionalized GNP (1 mg/mL) solution, at a weight ratio of 1:6. The irradiation of final solution was done under vigorous stirring for 4 h. After that, GNP–Ag nanocomposites were collected after centrifuge at 11,000 rpm for 40 min. The obtained composite was washed well with distilled water several times to remove reactants. The prepared rich sample was used in the next step to make nanofluids at different concentrations by adding specific amounts of distilled water. The