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Full Length Article

Numerical investigation of laminar convective heat transfer of graphene oxide/ethylene glycol-water nanofluids in a horizontal tube

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ABSTRACT

The study provides a numerical analysis of laminar forced convective heat transfer of graphene oxide nanosheets suspended in the mixture of water and ethylene glycol in laminar flow regime using single phase approach in a circular horizontal tube under constant heat flux conditions. The length and diameter of the simulation domain for numerical investigation are 2 m and 4.5 mm respectively. The effect of various flow conditions and weight concentrations have been investigated on local heat transfer coefficient, average heat transfer coefficient, friction factor, pressure drop and thermal performance factor of the nanofluids. The range of weight concentration and Reynolds number used in this study are 0.01–0.1 wt.% and 400–2000 respectively. The maximum percentage enhancement in average heat transfer coefficient was 13.04% for weight concentration and Reynolds number of 0.1 wt.% and 2000 respectively. The maximum pressure drop enhancement ratio was 2.12 at Reynolds number and weight concentration of 400 and 0.10 wt.%. The enhancement in heat transfer coefficient was found lower as compared to corresponding enhanced pressure drop for all weight concentrations. The thermal performance factor of nanofluids is less than one for all weight concentrations and nanofluids showed no advantage over base fluid as heat transfer fluid in laminar flow regime.
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1. Introduction

Nanofluids are very important novel engineering fluids because of their possible utilization in various sectors. It has been observed that nanofluids can provide higher thermal performance as compare to conventional thermal fluids such as water and ethylene glycol. So, there exists a strong possibility to improve the performance of thermal systems by using these engineering fluids.

Nanofluids have been tried for various applications including solar thermal systems [1], refrigeration systems as nano-refrigerant [2], vehicle cooling systems [3], electronic cooling systems [4], medical applications [5], lubrication systems [6], fuel cell cooling systems [7], hydraulic braking systems [8], combustion systems [9] and etc. The further details about the investigations on various kinds of nanofluids and their applications can be found in [10–14].

Nanofluid basically consist of two main components i.e. nanomaterial and the base fluid. There are number of ways to prepare the nanofluids either by mixing one or two kinds of nanomaterials in one or two types of base fluids (e.g. base fluid obtained by the combination of water and ethylene glycol). Nanomaterials can be obtained from metals (Al, Cu, Fe), metal oxides (Al_2O_3, TiO_2, CuO, Fe_3O_4), semiconductors (Cu_2O) or from non-metals (ND, CNT, GNP, GO). In a recent study, Mohebbi et al. [15] simulated forced convective heat transfer of water based three metal oxide (CuO, Al_2O_3, TiO_2) nanofluids using lattice Boltzmann method at very low Reynolds number (Re = 10–70) in a channel with extended surfaces. The increase in height of extended surfaces resulted enhancement in Nusselt number and this enhancement was higher for CuO nanofluids as compare to other two nanofluids. Alawi et al. [16] investigated the effect of nanoparticle shape, temperature and volume concentrations on viscosity and thermal conductivity of SiO_2, Al_2O_3, ZnO and CuO nanofluids using Koo and Kleinstreuer Model. They found that temperature has significant effect on

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Nomenclature

A, B, C	Correlation coefficients
C_p	Specific heat, J/kg K
D	Diameter of the channel, m
f_d	Darcy friction factor
h_{ave}	Average heat transfer coefficient, W/m^2 K
$h_{ave,\ e}$	Average heat transfer coefficient enhancement (%)
h_x	Local heat transfer coefficient, W/m^2 K
$h_{x,\ e}$	Local heat transfer coefficient enhancement (%)
L	Length of tube, m
N_x	Number of mesh elements in radial direction
N_y	Number of mesh elements in axial direction
P	Pressure, Pa
ΔP	Pressure drop, Pa
P_e	Pressure drop enhancement ratio, $\Delta P_f/\Delta P_b$
q''	Heat flux, W/m^2
Re	Reynolds number, $Re = \rho \bar{V} D/\mu$
r	radius of the channel, m
T	Temperature, K
V	Velocity of the fluid, m/s
$\bar{V}$	Average velocity of the fluid, m/s
x	Cartesian coordinate in axial direction, m
y	Cartesian coordinate in radial direction, m

Greek symbols

ρ	Density, kg/m^3
μ	Dynamic viscosity, Pa s
ϕ	Concentration of nanomaterial
k	Thermal conductivity, W/m K

Subscripts

a	Bulk (temperature)
b	Base fluid
f	Nanofluid
m	Weight (concentration)
s	Solid nanomaterial
v	Volume (concentration)
w	wall

Acronyms

CNT	Carbon nanotubes
EG	Ethylene glycol
G	Glycerol
GNP	Graphene nanoplatelets
GO	Graphene oxide nanosheets
MWCNT	Multi-walled carbon nanotubes
ND	Nano-diamond
PF	Performance factor
SIMPLE	Semi Implicit Method for Pressure Linked Equations
W	Water

viscosity of nanofluids and it decreases with the increase in temperature. However, an increase in thermal conductivity was found with the increase in temperature. While increased particle loading resulted in the enhancement of both viscosity and the thermal conductivity.

The distinct thermophysical properties of the graphene have made it strong candidate for various applications including thermal systems since the initial investigations of Novoselov et al. [17]. Yu et al. [18] experimentally investigated the augmentation in thermal conductivity of ethylene glycol based nanofluids having GO nanosheets and observed 61% increase in thermal conductivity at volume concentration of 5%. Meyer et al. [19] investigated the heat transfer and flow characteristics of water based nanofluids containing MWCNT for laminar, transitional and turbulent flow (Re = 1000–8000) regime in horizontal tube under constant heat flux of 13000 W/m^2 and at volume concentrations of 0.33%, 0.75% and 1.0% respectively. It was found that the friction factor of nanofluids were less than distilled water in laminar flow regime at same Reynolds number. They found that the enhancement in viscosity was more than four times of thermal conductivity which resulted in enhanced pumping requirements. They concluded that the water based MWCNT may provide no benefit over base fluid due to enhanced pressure losses in laminar flow regime. Ijam et al. [20] analysed the effect of temperature and particle loading on improvement in thermal conductivity of GO/EG-W nanofluids. A maximum enhancement of 11.7% was found in thermal conductivity at nanosheet loading and temperature of 0.1 wt.% and 318.15 K respectively. Sadeghinezhad et al. [21] observed significant improvement in convective heat transfer coefficient up to 160% with maximum enhancement of 14.6% in pressure loss for the turbulent flow of water based GNP nanofluids in horizontal tube. Heyhat et al. [22] performed experimentation to determine the augmentation in thermal conductivity of reduced GO/EG nanofluids for various controlling parameters including nanomaterial concentration and nanofluids temperature. The percentage enhancement in thermal conductivity was found to be 16.32% at weight concentration of 0.05%.

Kimiagar et al. [23] studied the effect of nanosheets concentration and temperature on thermal conductivity of reduced GO nanosheets dispersed in ethylene glycol. It was found that reduced GO/EG nanofluids provided maximum enhancement of 17.8% in thermal conductivity at weight concentration and temperature of 0.05 wt.% and 328.15 K respectively. Cabaleiro et al. [24] comprehensively investigated the thermophysical properties of GNP/EG-W nanofluids and obtained correlations for density, viscosity and thermal conductivity of nanofluids. They also observed that there may be no significant improvements in heat transfer of GNP/EG-W nanofluids over the base fluid and rather it will enhance pumping requirements. Ranjbarzadeh et al. [25] studied the heat transfer and flow features of GO/W nanofluids in copper tubes covered by cross flow of air behaving as heat exchanger. They concluded that the maximum increase in Nusselt number and friction factor was 51.4% and 21% respectively at nanofluids volume concentration and Reynolds number of 0.2% and 3250 respectively. In another study, Ranjbarzadeh et al. [26] experimentally investigated the heat transfer intensification for turbulent flow of water based GO nanofluids in circular shape channel under isothermal conditions with volume concentrations and Reynolds number of 0.025–0.1% and 5250 & 36,500 respectively. It was found that the highest enhancement in convective heat transfer coefficient and pressure drop were 40.3% and 16% respectively at tested conditions.

Yazid et al. [27] comprehensively reviewed the application of various kinds of nanofluids with CNT as base fluid in heat and mass transfer applications for different channels such as straight tubes and heat exchangers. They also discussed various equations to assess the thermohydraulic performance of nanofluids. It was concluded that the pressure drop and pumping power is enhanced with the addition of nanoparticles in base fluid however their effect can be minimized by maintaining low concentration of nanofluids. The covalent functionalization technique was

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