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Research Paper

Effects of functionalized single walled carbon nanotubes on thermal performance of antifreeze: An experimental study on thermal conductivity

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HIGHLIGHTS

- Suspending SWCNTs in antifreeze with different concentrations using two-step method.
- Thermal conductivity improved with increasing concentration and temperature.
- Presenting a practical correlation for predicting the thermal conductivity of this nanofluid.
- Defining thermal performance as the ratio of heat transfer coefficient to pressure drop.
- Nanofluid is efficient as long as relative viscosity is lower than the 0.465 power of the thermal conductivity ratio.

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ABSTRACT

In this experimental work, the antifreeze composed of 50 vol.% water and 50 vol.% ethylene glycol has been used as the base fluid. The functionalized single walled carbon nanotubes (F-SWCNTs) with different volume fractions (0.025, 0.055, 0.08, 0.125, 0.25, 0.53 and 0.65%) have been suspended to the base fluid by ultrasonic waves. The KD2 Pro Thermal Properties Analyzer was employed to measure thermal conductivity of the prepared samples at different temperatures. Results showed that the thermal conductivity improves proportionally with augmenting the concentration and temperature. Measurements also indicated that in greater volume fractions ($\varphi > 0.53\%$), temperature rise has a greater influence on the nanofluids thermal conductivity. Since no valid and applicable correlation is available to predict the thermal conductivity of F-SWCNTs/EG-water nanofluid, a correlation has been offered for predicting the thermal conductivity of this nanofluid using experimental results. The maximum value of deviation boundary was 2.4%. Finally, forced convective heat transfer in a smooth tube in absence and presence F-SWCNTs was investigated. Thermal performance of antifreeze (η), defined as the ratio of heat transfer coefficient to pressure drop, was analyzed and results made a border for the use of present nanofluids. The argumentations indicated that the present nanofluid was efficient as long as relative viscosity is lower than the 0.465 power of the thermal conductivity ratio.

1. Introduction

Water is used as an effective working fluid in the majority of heat transfer systems. Ethylene glycol (EG, antifreeze) is also used as a modifier that lowers the water freezing point. A 50:50 mixture of EG and water remains liquid down to −37 °C. Due to these proper properties, water-EG is employed in thermal applications such as HVAC systems processors, electronics equipment, automotive engines, solar collectors and high power transformers for cooling or heating proposes [1–7]. However, the thermal conductivity of this mixture is lower than that of pure water. Liquid suspension of nanoparticles, which forms nanofluids, is a technique to enhance thermal conductivity of fluids. According to several studies, nanofluids have greater thermal conductivity than conventional coolants [7–13]. Researchers have also reported that the thermal conductivity of nanofluids can be organized by physical and chemical properties of nanoparticles and the base fluid. Recently, nanoparticles have been used in many thermal applications [14–26]. The use of proper kinds of nanoparticles as an additive to water-EG mixture is very imperative to attain a high heat transfer rate. The nanofluids thermal conductivity is a main property that must be regulated.

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Nomenclature

C_p	specific heat (J/kg K)
d	diameter (nm)
dev	deviation
f	turbulent friction factor
g	gravity acceleration (m/s^2)
h	convective heat transfer
k	thermal conductivity (W/m K)
m	mass (kg)
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
T	temperature (°C)
$\bar{V}$	mean flow velocity (m/s)

Greek letters

Δp	pressure difference (Pa)
η	thermal performance
φ	solid volume fraction (%)
μ	dynamic viscosity (kg/ms)
ρ	density (kg/m^3)

Subscripts

bf	base fluid
Exp	experimental data
nf	nanofluid
pred	predicted value
EG	ethylene glycol
SWCNTs	single walled carbon nanotubes
p	solid particles

As declared above, various volume ratios of water-EG is typically used for lowering the water freezing point in winter. Due to several applications of this mixture, many empirical studies have been conducted to specify the thermal conductivity of nanoparticles-contained antifreeze. A review on these studies is reported in Table 1. In these studies, water and ethylene glycol (antifreeze) were mixed with various ratios, and nanoparticles were then dispersed in them. Studies emphasized that adding nanoparticles to water-EG mixture can improve its thermal conductivity.

A review of literature on nanofluids [37–41] showed that they can be good substitutes for conventional coolants in engine cooling systems. Therefore, adding nanoparticles to the standard coolants can improve the efficiency of radiators as a component of engine cooling systems. This can be regarded as aerodynamic element in designing the front part of a vehicle. Moreover, these studies reported that the use of nanofluids as coolant results in reduced drag coefficient (drift), parasite loss, friction, abrasion, and improved efficiency of water pumps and fuel.

Literature review showed that there are few studies on the thermal conductivity of nanotubes in water-EG binary mixtures. Carbon nanotubes have higher thermal conductivity, lower specific gravity, and higher aspect ratio than oxide nanoparticles. Since the single walled carbon nanotubes (SWCNTs) have very high thermal conductivity, this study addressed the analysis and measurement of the thermal conductivity of SWCNTs/EG-water. In addition, because of the lack of a model for estimating thermal conductivity of this nanofluid, a new function, "solid-temperature volume fraction" is proposed for thermal applications using the obtained experimental results. Finally, because of importance of forced convective heat transfer in the design of heat transfer equipment, assessment of thermal performance of the nanolubricant is performed in a typical tube.

2. Experimental process

2.1. Preparation of nanofluid samples

Preparing the nanofluid samples is the important step of nanofluid testing process. This is because even distribution of nanotubes in the base fluid is essential. In this way, suitable devices, such as ultrasonic instrument and magnetic stirrer, can be used to attain suspension steadiness against nanotubes deposition. Furthermore, functionalization of carbon nanotubes with some organic molecules, such as COOH, can contribute to better suspension of nanotubes.

To this end, the antifreeze composed of 50 vol.% water and 50 vol.% ethylene glycol was used as the base fluid. The functionalized single walled carbon nanotubes with different solid volume fractions (0.025, 0.055, 0.08, 0.125, 0.25, 0.53 and 0.65%) were added to the base fluid, using a two-step method. The masses of nanotubes for samples preparation were specified by a sensitive electronic balance (accuracy of 1 mg). It is worth noting that the agglomeration phenomenon was observed in the solid volume fraction of higher than 0.65%, which resulted in nanotube deposition. The chemical and physical properties of water and ethylene glycol (antifreeze) are presented in Table 2. The properties of functionalized single walled carbon nanotubes are presented in Table 3.

Table 1
A review on previous studies on thermal conductivity of nanoparticles-contained antifreeze.

Author	EG-water (vol.%)	Nano-additives	Maximum enhancement
Yu et al. [27]	45–55	Al_2O_3	11.6%
Kumaresan and Velraj [28]	30–70	MWCNTs	19.75%
Sahooli and Sabbaghi [29]	65–35	CuO	66%
Mojarrad et al. [30]	50–50	Al_2O_3	5.5%
Teng and Yu [31]	50–50	MWCNTs	48.8%
Suganthi et al. [32]	50–50	ZnO	17.26%
Hemmat Esfe et al. [33]	40:60	CuO	36.97%
Hemmat Esfe et al. [34]	40–60	MgO	35%
Hemmat Esfe et al. [35]	60–40	Al_2O_3	35%
Soltanimehr and Afrand [36]	40–60	MWCNTs	34.7%

Table 2
Chemical and physical properties of water and ethylene glycol [34].

Parameter	Value	
	Water	Ethylene glycol
Chemical formula	H_2O	$C_2H_6O_2$
Molar mass	18.01528 (g/mol)	62.07 (g/mol)
Appearance	Almost colorless, transparent	Clear, colorless liquid
Odor	Odorless	Odorless
Density	998.21 (kg/m^3)	1113.2 (kg/m^3)
Thermal conductivity (@20 °C)	0.6 (W/m K)	0.244 (W/m K)
Viscosity (@20 °C)	1 (cP)	16.1 (cP)