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Thermophysical properties of Single Wall Carbon Nanotubes and its effect on exergy efficiency of a flat plate solar collector

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Abstract

In order to enhance thermal efficiency of a flat plate solar collector, the effects of thermo-physical properties of short Single Wall Carbon Nanotubes (SWCNTs) suspended in water was investigated in this study. Sodium dodecyl sulphate was used as a dispersant for preparing a stable nanofluid. Subsequently, the nanofluid was comprehensively characterized by particle size measurement and spectroscopic technique. Specific heat with the increase of particle loading and temperature was investigated. Thermal conductivity increment also showed a linear dependence on particle concentration and temperature. Viscosity of the nanofluids and water reduced with the increase of temperature and increased with the particle loading. Using improved thermo-physical properties of the nanofluid, the maximum energy and exergy efficiency of flat plate collector was enhanced up to 95.12% and 26.25% compared to water which was 42.07% and 8.77%, respectively. This low exergy efficiency shows that flat plate collectors still require substantial enhancement. To the authors' knowledge, SWCNTs–H_2O was used as the functioning fluid for the first time to investigate both the thermos-physical properties as well as the increase in thermal efficiency of a flat plate solar collector.

Keywords: Specific heat; Thermal conductivity; Viscosity; Nanofluid; Exergy; SWCNTs

1. Introduction

Nanofluids are new addition to the family of fluids prepared by immersing nanoparticles in conventional fluids such as water, oils, ethylene glycol or coolants. In general, these nanoparticles used in nanofluids are metals, metal oxides or carbon nanotubes (CNTs), in diverse allotropic forms. Choi et al. (2001) first reported studies on nanofluids and also explored the potentials of these nanofluids, precisely in heat conduction applications. With regards to thermal engineering applications, enhancement of upto 60% in thermal conductivity for water based nanofluids was reported in literature (Keblinski et al., 2008; Yu et al., 2008).

One of the utmost extraordinary findings of the last decade are carbon nanotubes (CNTs) (Iijima and Ichihashi,

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Nomenclature

A_c	collector area (m^2)	$\dot{Q}_o$	heat loss rate to the ambient (W)
C_p	specific heat (J/kg K)	$\dot{Q}_s$	energy rate engrossed (W)
d	diameter of pipe (m)	T_a	ambient temperature (K)
$\dot{E}x_{in}$	exergy rate at inlet (W)	R	ideal gas constant (J/K mol)
G_c	global solar irradiation	h_{in}	specific enthalpy at inlet (J/kg)
Δ	difference	h_{out}	specific enthalpy at outlet (J/kg)
$\dot{E}x_{out}$	exergy rate at outlet (W)	μ	coefficient of viscosity
$\dot{E}x_{dest}$	rate of irreversibility (W)	T_{out}	output temperature (K)
$\dot{E}x_{heat}$	exergy rate received from solar radiation (W)	bf	basefluid
$\dot{E}x_{work}$	exergy output rate from the system (W)	T_s	sun temperature (K)
$\dot{E}x_{mass,in}$	exergy rate associated with mass at inlet (W)	T_{sur}	surrounding/ambient temperature (K)
$\dot{E}x_{mass,out}$	exergy rate associated with mass at outlet (W)	M	viscosity (N s/m^2)
		τ	transmittance coefficient of glazing
$\dot{S}_{gen}$	entropy generation rate (W/K)	A	absorptance coefficient of plate
$\dot{Q}_{sun,in}$	energy gain rate (W)	$\tau\alpha$	effective product transmittance–absorptance
τ	shear stress	Φ	nanoparticles volume fraction (%)
I	intensity of solar radiation (W/m^2)	s_a	entropy generation to surrounding (J/kg K)
Pnf	nanofluid	s_{in}	entropy generation at inlet (J/kg K)
k_p	thermal conductivity of nanoparticle (W/m K)	s_{out}	entropy generation at outlet (J/kg K)
K	loss coefficient (dimensionless)	Pm	density (kg/m^3)
$\dot{m}$	mass flow rate (kg/s)	Σ	overall entropy production (J/kg K)
$\dot{W}$	work rate or power (W)	F	friction factor
η	collector efficiency	H	specific enthalpy (J/kg)
P	fluid pressure (Pa)	$\dot{\gamma}$	shear strain rate
q	convective heat transfer rate (W)	T_{in}	input temperature (K)
k	thermal conductivity (W/m K)	P	nano particle

1993; Choi et al., 2001). Depending on their structure, they have several unusual properties, such as high electrical and thermal conductivities. In particular, thermal properties of CNTs have attained a great deal of dedication (Tans et al., 1997; Saito et al., 1998; Mizel et al., 1999; Hone et al., 2000; Zhang et al., 2003; Wen and Ding, 2004; Duong et al., 2008; Sun et al., 2008; Harish et al., 2012). Both experimentally and numerically high thermal conductivities of CNTs have been reported in literature (Berber et al., 2000; Kim et al., 2001; Maruyama, 2003; Yu et al., 2005; Pop et al., 2006). Therefore, CNTs are naturally expected to have higher thermal conductivity enhancements in nanofluids as compared to other nanoparticles. However, this unusual increase could not be supported by consequent studies reported (Xie et al., 2003; Wen and Ding, 2004; Assael et al., 2005; Liu et al., 2005; Ding et al., 2006; Garg et al., 2009). Since unique mechanical, electrical and structural properties are possessed by Single Wall Carbon Nanotubes (SWCNT), they have attracted the attention of the researchers (Dresselhaus and Avouris, 2001; Baughman et al., 2002). SWCNT possesses outstanding thermal and chemical stabilities with high-tensile strength and extremely light weight (Jha and Ramaprabhu, 2012). The specific heat of SWCNT has also been investigated by several researchers (Mizel et al., 1999; Hone et al., 2000; Zhang et al., 2003; Pradhan et al., 2009). Most of the presented reports in literature are focused on multi walled carbon nanotubes (MWCNTs), whereas limited studies are found to be conducted on thermo-physical properties of SWCNTs based nanofluid.

Several researchers have proposed different techniques and models for obtaining stable nanofluid suspensions (Li et al., 2007; Jiang et al., 2010; Ghadimi et al., 2011; Said et al., 2013; Sajid et al., 2014). Some important parameters such as the length of the CNTs, the purity level, preparation method and pH of the solution and thermophysical properties should be known in order to make a direct comparison between experimental and theoritical results. In this context, stable suspension of SWCNTs based nanofluid using SDS surfactant was prepared to get more accurate results.

Heat transfer enhancement using nanofluids in solar thermal collectors is one of the main issues in saving energy. Several studies related to nanofluids and its uses in solar collectors are reported (Link and El-Sayed, 2000; Kameya and Hanamura, 2011; Mercatelli et al., 2011a,b, 2012; Sani et al., 2011; Saidur et al., 2012). Tyagi et al. (2009) reported the efficiency enhancement for low values of the volume fraction of nanoparticles. However, for a volume fraction higher than 2%, the efficiency stayed closelypersistent. Otanicar et al. (2010) found that the additionof a little amount of nanoparticles enhanced the