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Superior thermal features of carbon nanotubes-based nanofluids – A review

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ABSTRACT

Recent progresses in research on several key thermal features and potential applications of carbon nanotubes-laden nanofluids are reviewed and addressed. Besides briefing on the preparation of these nanofluids, available studies on conduction, convection and boiling heat transfers of this specific class of nanofluids are discussed in detail. Effects of different parameters such as concentration of carbon nanotube and temperature on thermal conductivity, convective heat transfer coefficient, and boiling critical heat flux are also demonstrated. It is found that despite inconsistencies among available data and inconclusive heat transfer mechanisms, substantial increase in these thermal features of carbon nanotubes-nanofluids compared to their base fluids remain undisputed. In addition to the work on specific heat and thermal diffusivity, available theoretical models and heat transfer mechanisms of this particular type of nanofluids are presented and discussed. Research on a new class of nanofluids termed as "ionanofluids" is also reported. Review reveals that ionanofluids exhibit superior thermal properties compared to their base ionic liquids and these properties further increase with increasing concentration of carbon nanotube as well as fluid temperature to some extent. Carbon nanotubes based both nanofluids and ionanofluids show great potential as advanced heat transfer fluids in many important applications.

Contents

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Nomenclature

c_p	specific heat (J/kg K)
d	diameter (m)
h	heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m K)
q	heat flux (W/m^2)
r	radius (m)
t	thickness of interfacial layer (m)
T	temperature (K or °C)
R_k	Kapitza resistance (K m^2/W)

Greek symbols

ϕ	particle volume fraction
ρ	density (kg/m^3)
μ	dynamic viscosity (kg/m s)
ψ	sphericity

Subscripts

f	base fluid
eff	effective
inf	ionanofluid
il	ionic liquid
lr	layer
nf	nanofluid
p	particle

Abbreviations

BHTC	boiling heat transfer coefficient
CHF	critical heat flux
CNT	carbon nanotubes
DIW	deionized water
EG	ethylene glycol
EO	engine oil
MWCNT	multi-wall carbon nanotubes
NF	nanofluids
PAO	poly-alpha-olefin
SO	silicone oil
SWCNT	single wall carbon nanotubes
THWM	transient hot-wire method
W	water

1. Introduction

Carbon nanotubes (CNT) are often known as wonder nanomaterials which have very large aspect ratio and a very broad range of unique thermal, mechanical, chemical, optical and electronic properties. The remarkable and unique properties of carbon nanotubes have placed them right among the hottest topics in multidisciplinary fields, particularly in materials sciences. Thus research on carbon nanotubes has become a hot topic in multidisciplinary fields. Although innovation of CNT is attributed to a Japanese scientist, Iijima in 1991 [1], Endo and co-workers [2] first reported TEM images of CNT in 1976. Iijima [1] demonstrated synthesizing of needle-like nano-sized (diameter ranging between 4 and 30 nm) carbon tubes using arc-discharge evaporation technique. Later in 1993 the growth process of single walled CNT was reported by two research groups, one by Iijima and Ichihashi [3] and the other by Bethune and co-workers [4]. Since its revolutionary discovery in early 1990s carbon nanotubes have attracted immense interest from both the academic and the industrial communities due to their fascinating properties and potential applications in numerous fields such as aerospace, automotive, electronic, optical, and energy conversion [5,6]. These nanotubes can behave like metals or semiconductors and can conduct better electricity and heat compared to copper and diamond, respectively. Thus they can be used in nanoelectronics like diodes and transistors and in supercapacitors as electromechanical actuators and sensors, in lithium-ion batteries, as well as fillers in composite materials such as polymer-based composites [6–8]. The remarkable thermal property of carbon nanotube is their ultra-high thermal conductivity (2000–6000 W/m K) which is order of magnitude higher compared to those of the metallic or oxide nanomaterials such as aluminum (237 W/m K) and aluminum oxide (40 W/m K) that are commonly used in nanofluids as heat transfer enhancer. Thus like carbon nanotube, nanofluids (NF) which are a new class of advanced heat transfer fluids have attracted great interest from researchers worldwide because of their anomalously high thermophysical properties and potentials applications in numerous important fields such as microelectronics, MEMS, microfluidics, transportation, manufacturing, instrumentation, medical, and HVAC systems [9–19]. Even after almost two decades of innovation of these new fluids (i.e., nanofluids) [20] and having extensive research performed thereafter, reported data are still scattered and the underlying mechanisms for anomalous thermal features particularly thermal conductivity of nanofluids are still inconclusive and not well understood [9–12,19]. Researchers are still debating and facing enormous challenges to uncover the true mechanisms behind such anomalously thermal properties of nanofluids.

With such ultrahigh thermal conductivity of carbon nanotubes, their nanofluids exhibit much higher thermal features such as thermal conductivity, heat transfer coefficient and boiling heat flux as compared to their base fluids as well as nanofluids containing other types of nanomaterials [9–13,20–31]. With a very large aspect ratio carbon nanotubes also exhibit excellent dispersion behavior in most of the commonly used solvents. In order to fully utilize these superior thermal characteristics, it is very important to prepare CNT-nanofluids that show long term stability and well-dispersion of CNT. Literature results on the thermal features of CNT-nanofluids reveal their great potentials as advanced heat transfer fluids. There is

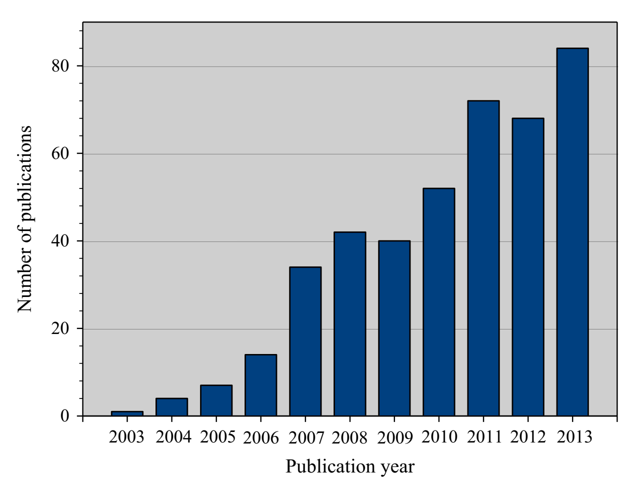

Fig. 1. Year-wise publications on CNT-nanofluids (publications searched by topic “nanofluids” and refined by “carbon nanotubes” in Web of Science on December 20, 2013).