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A review of the impact of preparation on stability of carbon nanotube nanofluids☆

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ABSTRACT

Carbon nanotube (CNT) has the highest thermal conductivity among the nanoparticles that were discovered so far. Attempts to utilize them as heat transfer fluids by dispersing them into any kinds of base fluids called CNT nanofluids have been thoroughly conducted. However, one of the challenges faced by many researchers in applying their prepared CNT nanofluids is to maintain its homogeneous state and long-term stability. This paper presents an inclusive review on the preparation techniques and the reported period of stability of stationary CNT nanofluids. The characteristics of available treatment such as chemical treatment (covalent and non-covalent) and physical treatment methods have been systematically analyzed. Finally, the challenges and future trends of CNT nanofluids are discussed.

Contents

1. Introduction

Rapid emergence of nanosciences and nanotechnologies researches from a few decades ago, has brought it at the forefront of today's science and technology. The discovery of carbon nanotubes (CNTs) perhaps contributed to the nanotechnology revolution owing to its superior thermal, physical, optical and electrical properties and has ultimately evolved into one of the most intensively studied nanomaterials. A Japanese scientist by the name of Iijima [1] is famously known for his discovery of CNTs. According to Monthioux and Kuznetsov [2] however, it turns out that the discovery of CNTs goes back much further than the 1990s. As a matter of fact, CNTs with multi walled configuration, also known as multi-walled carbon nanotubes (MWCNT) were first discovered in 1951 by Russian scientists Radushkevich and Lukyanovich [3]. Forty years after the discovery of MWCNT by Radushkevich and Lukyanovich [3], another type of CNT with single wall, also known as single walled carbon nanotube (SWCNT) was discovered by Iijima and Ichihashi [4] in 1993. One of the notable characteristics of CNTs is having a remarkably high thermal conductivity. Previous researchers have reported a high thermal conductivity of SWCNT and MWCNT, which is higher compared to other nanoparticles (Fig. 1).

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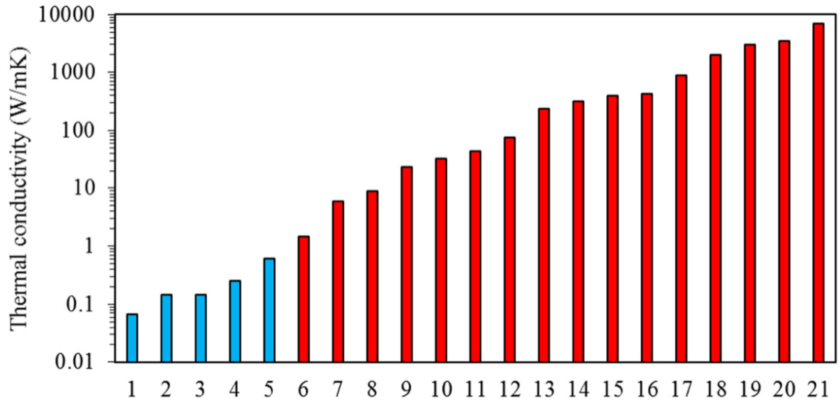

1	Refrigerant (R113) [5]	8	TiO_2 (Rutile) [5]	15	Cu (copper) [6]
2	Poly-alpha-olefin oil [7]	9	ZnO (zink oxide) [6]	16	Ag (Silver) [6]
3	Engine oil [8]	10	Al_2O_3 (Aluminium oxide) [6]	17	C (Diamond) [6]
4	Ethylene glycol [6]	11	MgO (Magnesium oxide) [9]	18	C (Graphite) [6]
5	H_2O (Water) [6]	12	CuO (Copper (II) oxide) [10]	19	MWCNT (14 nm) [11]
6	SiO_2 (Silica) [6]	13	Al (Aluminum) [6]	20	SWCNT (1.7 nm) [12]
7	Fe_3O_4 (Iron oxide) [9]	14	Au (gold) [6]	21	SWCNT (1.0 nm) [13]

Fig. 1. Thermal conductivity of selected metals, ceramics (or metallic oxides), and liquids at room temperature [5–13]. Note: blue colored bar indicates liquid whilst red colored bar indicates solid. (For interpretation of the references to colors in this figure legend, the reader is referred to the web version of this article.)

The discovery of high thermal conductivity of nanoparticle has triggered interests in researches that utilized heat transfer fluids. The first attempt for this concept was realized by Choi [14] as they discovered an anomalously high thermal conductivity of nanofluids compared to base fluid. Consequently, a lot of research effort has been reported in the literature on applying different nanofluids in energy harvesting system [15,16] and cooling system [17–28]. The results showed the enhancement of heat transfer due to the presence of nanoparticle in the fluid. In conjunction to the potential of nanofluids as an advanced heat transfer fluid and the realization of the highest thermal conductivity of CNTs, Choi and his colleagues [29] were possibly the first who had studied CNT contained nanofluids whereby MWCNT nanoparticles with concentrations up to 1 vol.% were added into poly-alpha olefin (PAO) oil. They found that the maximum thermal conductivity ratio (k_{nf}/k_{bf}) has exceeded 2.5.

This paper reviews the latest findings on long-term stability due to preparation techniques of CNT nanofluids. It is noteworthy that there are few other reviews that have been published on the subject prior to the current article [30,31]. However, research trends from Scopus database as shown in Fig. 2 strongly suggest that the research in CNT contained nanofluids is increasing every year and the past couple of years, that number has dramatically arisen as it received numerous attention by researchers around the world. In addition, the aspect covered in the aforementioned review articles is mainly focused on the thermal performance aspect of CNT nanofluids (i.e., thermal conductivity). Yet, little are known about the preparation and the stability conditions of CNT nanofluids. Concurrent to the statements above, we believe that now is a suitable time for the latest review on the subject.

2. Types and preparation techniques

2.1. CNTs

Although carbon is ubiquitous in nature, CNTs are not, as it is a man-made form of carbon. Arc discharge, laser ablation, chemical vapor deposition (CVD), as well as diffusion and premixed flame methods are the major synthesis methods for SWCNT and MWCNT [32–34]. The shape of CNT can be categorized into two, namely the SWCNT and MWCNT. Conceptually, SWCNT is made by rolling a graphene sheet into a seamless cylinder as shown in Fig. 3. Meanwhile more rolled-up graphene sheets formed MWCNT (Zhang and Li [35]).

2.2. CNT nanofluids

The first and utmost important step in applying CNTs to improve the thermal conductivity of fluids is the preparation of CNT nanofluids.

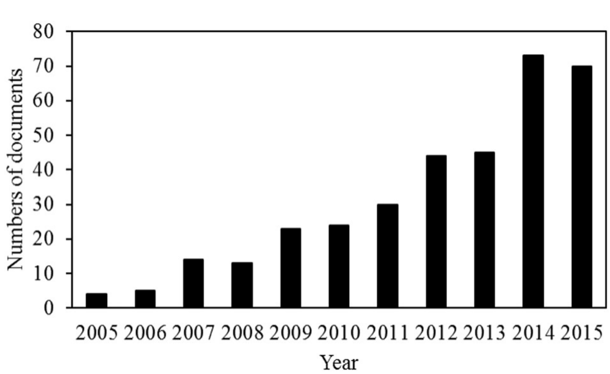

Fig. 2. Number of articles published from 2005 to 2015. Records retrieved from Scopus using 'nanofluid carbon nanotube' as the keyword. Documents that were published include journal, conference articles, and books.

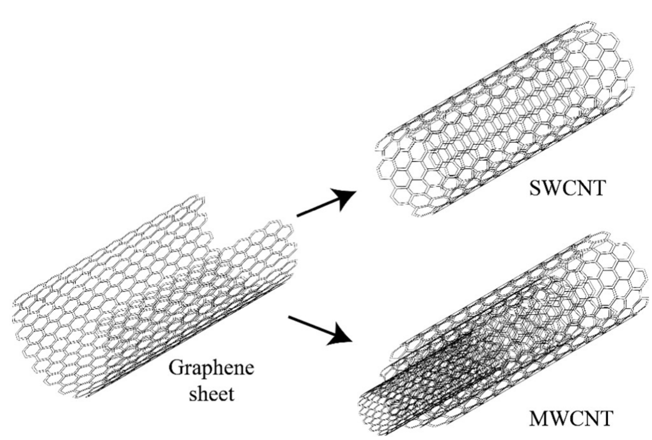

Fig. 3. Schematic diagrams of single-wall carbon nanotube (SWCNT) and multi-wall carbon nanotube (MWCNT) made from rolled-up graphene sheet.