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Review

A comprehensive review on graphene nanofluids: Recent research, development and applications

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ABSTRACT

An overview of experimental results about the heat transfer capabilities of graphene nanofluids is reviewed. It shows that a number of publications are available on this issue and only few studies provide quantitative estimates on a complete set of experimental conditions so far. This research work includes experimental results about the capabilities of graphene nanofluids and summarizes the recent progress on preparation and evaluation methods, the ways to enhance the stability of graphene nanofluids and future applications in various fields of energy. Thermo-physical and optical properties of graphene nanofluids along with the heat transfer performance have also been reported in this review paper. Various challenges associated with the use of graphene nanofluids in actual applications has also been reported. It is expected that it could be a quick reference guide to have an overview of the different heat transfer phenomena in graphene nanofluids and the most essential parameters that influence the expected thermal performance of graphene nanofluids.

Contents

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1. Introduction

Heat removal and management is a major concern for any technology that deals with high power and small size. Use of nanofluids to address these issues has been subject of interest by the many scientists around the world. In many cases, a nanofluid can be custom made to fit a particular need and can act as a flexible cooling method, adapting to the requirements of a specific system. In essence, nanofluids have the potential to become the world's first smart/adaptable coolant [1,2].

Nanofluids, coined by Choi and Eastman [3], are multiphase systems with a base matrix host fluid and a stable colloidal suspension of nanometer sized particles. Nanofluid can be produced in a one step process by creating the host fluid and nanoparticles together, or created separately and mixed in a two-step process [4]. Nanofluid have been studied extensively since their creation due to their often times anomalous and unique thermal transport characteristics. Nanofluid have also proven to be quite valuable in terms of the scientific knowledge gained from their study and their nearly unlimited industrial and commercial applications [5,6]. Few research works have expanded the science of nanofluids into a previously unexplored field, that of cryogenic nanofluids. Cryogenic nanofluids are similar to traditional nanofluids and utilize nanometer sized particles [4,7]. Cryogenic nanofluids received a great interest due to the fact that they combined the extreme temperatures inherent to cryogenics with the customizable thermal transport properties of nanofluids. Therefore, this type of nanofluid have created a potential interest for next generation cryogenic fluids with enhanced thermophysical properties. Traditional nanofluids consist of any type of fluid or fluid mixture and can have one or more variety of nanoparticles, dispersants, etc. acting as the inclusion phase [8,9]. The variety of nanofluids is truly staggering and indeed, a new nanofluid can be created by simply mixture of different base fluids or nanoparticle together. Even slight changes in the creation methodology of nanofluids can lead to significant changes in the end result [8].

The heat transfer applications directly or indirectly affect people's daily life and require an additional research in order to improve their efficiencies [10]. Along with an advancement in manufacturing techniques, the products that have small size, high heat flux and non-uniform heat flux have occupied a significant portion in many industries. This trend is expected to continue unabated for the coming years and therefore heat rejection solutions are facing huge demands [11]. From an engineering point of view, forced convection utilizing liquid coolants in laminar or turbulent flow regimes are always a key heat transport solution for the examples stated above [12,13].

However, these techniques usually lead to dramatically higher pressure loss and increase pumping power [14]. Also, with low thermal conductivity and high viscosity of common heat transfer liquids including water, ammonia, ethylene glycol and mineral oil are the major issues in heat transfer applications. The convective thermal performance was often inefficient and created barriers in designing small heat rejecting devices. Therefore, an innovative coolant like nanofluid with improved heat transfer properties is desired [15,16].

In order to increase the fluid heat transfer coefficient, many efforts have been made on heat transfer fluid, properties of surfaces (extension, shape, roughness, etc.) and fluid motion (laminar or turbulent). Recently, a number of studies have been conducted on the use of carbon based nanostructures to prepare nanofluids [17]. The graphene is one of the most studied materials for this decade [18,19]. Graphene, a single-atom-thick sheet of hexagonally arrayed sp^2-bonded carbon atoms, which has received much attention since it was discovered by Novoselov et al. [20] and attracted a lot of attention because of its unique electrical properties such as very high carrier mobility. In graphene, carbon atoms are densely organized in a regular sp^2 bonded atomic-scale honeycomb (hexagonal) pattern and this pattern is a basic structure for other sp^2 carbon bonded nano-structure materials [21] such as carbon nanotubes [22] and fullerene [23]. In recent years, a significant number of studies have been conducted on graphene due to its unique thermal, electrical, optical, mechanical and other relevant characteristics [24]. Characterization of graphene provides an important part of graphene research and involves measurements based on various spectroscopic and microscopic techniques [5,25]. Importance of graphene nanoparticles and their benefits compared to other nanoparticles have been investigated and it could be stated that the graphene nanoparticles possess the following advantages:

1. Easy to synthesis and longer suspension time (More stable)
2. Larger surface area/volume ratio (1000 times larger)
3. Higher thermal conductivity
4. Lower erosion, corrosion and clogging
5. Lower demand for pumping power

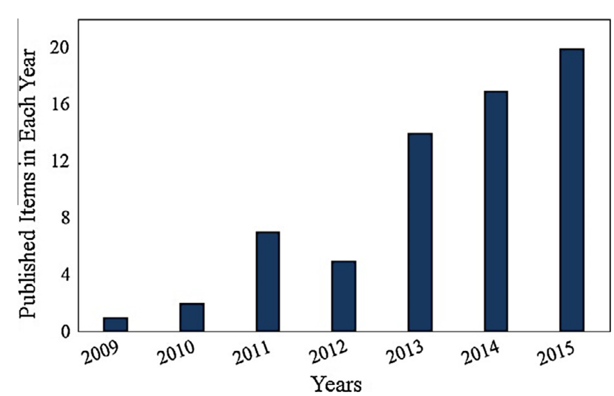

Fig. 1. Number of JCR articles per year, as reported by Journal of Citation Report, Web of Science (http://apps.webofknowledge.com), from 2009 and updated to October 2015 retrieved via the keyword "nanofluid" and "graphene" in the topic of the paper.