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A review on preparation, characterization, properties and applications of nanofluids

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ABSTRACT

Selection of suitable heat transfer fluid for heat dissipation is an important consideration in the design of heat exchanging systems. Nanofluid, a colloidal mixture made of a base fluid and a nanoparticle, is a new generation of heat transfer fluids becoming a high potential fluid in heat transfer applications due to enhanced thermal conductivity. Research studies about nanofluids are on the rise owing to the mounting interest and demand for nanofluids as heat transfer fluids in a wide variety of applications. Recently, nanofluid technology has a new dimension of impregnating two or more nanoparticles in base fluids, namely hybrid or composite nanofluids. This paper reviews the preparation of metal and metal oxides nanofluids and hybrid nanofluids and the various techniques used to study the physical and chemical characteristics of nanofluids. Thermo-physical and heat transfer properties of nanofluids including the improved thermal conductivity, viscosity and specific heat models for nanofluids are presented. Finally, various application areas of nanofluids, such as transportation, electronic cooling, energy storage, mechanical applications etc. are discussed.

Contents

Abbreviations: CNT, carbonnanotube; CTAB, centrimoniumbromide; HTC, heattransfercoefficient; PVP, polyvinylpyrrolidone; SDBS, sodiumdodecylbenzenesulfonate; SEM, scanningelectronmicroscope; TEM, transmissionelectronmicroscope; XRD, X-raydiffraction; FT-IR, fouriertransforminfraredspectroscope; DLS, dynamiclight scattering; TGA, thermogravimetricanalysis; ATF, aviationturbinefuel; HRTEM, highresolutiontransmissionelectronmicroscope; PU, polyurethane; AFM, atomicforce microscopy; VSM, vibratingsamplemagnetometer

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1. Introduction

Heat exchangers are widely used in many engineering applications, such as chemical industry, power production, food industry, environment engineering, waste heat recovery, air conditioning, automobile radiators and refrigeration. Efforts have been made to enhance heat transfer rate in heat exchangers to reduce the heat transfer time and improve energy efficiency. Although various techniques have been applied to enhance heat transfer, their performances are often limited by the low thermal conductivities of the heat transfer fluids, which limit the performance enhancement and compactness of heat exchangers. With the growing demands of modern technology for miniaturization of devices, there is a need to develop new types of heat transfer fluids that are more effective in terms of heat transfer performance. It has been proved that the dispersion of small amounts of nano-sized (< 100 nm) solid nanoparticles in base fluids, commonly known as nanofluids, enhance thermal conductivity and improve the thermal performance of heat transfer systems. The concept of nanofluids was coined by Stephen U.S. Choi in the year 1995 at Argonne National Laboratory in U.S.A. [1]. Nanofluid is a colloidal mixture in which the properties of both the nanoparticles and the base fluid contribute to the change in the transport and thermal properties of the basefluid [2]. Nanofluids are fundamentally characterized by the fact that Brownian agitation overcomes any settling motion due to gravity. Thus, a stable nanofluid is theoretically possible as long as particles stay small enough (usually 100 nm) [3]. Keblinski et al. [4] have reviewed literatures about the properties of nanofluids and future challenges and reported that the development of nanofluids is still hindered by several factors such as the lack of good theoretical property models, agreement between theoretical and experimental results, poor characterization of suspensions, and the lack of theoretical understanding of mechanism.

Nanocomposites, i.e., composites containing two different dispersed particles in the nanometer range, are significant part of nanotechnology and one of the fastest growing areas in materials science and engineering [5,6]. The hybrid nanofluids are new kind of nanofluids, which can be prepared by suspending two or more nanoparticles in the base fluid, in other words hybrid (composite) nanoparticles in base fluid. A hybrid nanoparticle is a substance which combines physical and chemical properties of the constituent materials simultaneously and provides these properties in a homogeneous phase. Furthermore, the hybrid nanofluid is expected to yield better thermal conductivity compared to individual nanofluids due to synergistic effect [7]. A significant amount of research has been done regarding the properties of these composites [8] and hybrid materials consisting of carbon nanotubes (CNTs) which have been used in electrochemical-sensors, bio- sensors, nanocatalysts, etc. [7] but the use of these hybrid nanomaterials in base fluids has not developed as such. Reported research work on hybrid nanofluids is very limited and a lot of experimental studies are still to be done.

In this context, a detailed review of nanofluid research works assumes a great significance as it would facilitate the researchers to update the recent developments and realize the potential research gap in the field of nanofluid. This paper focuses on the existing knowledge and research gap in all fields of nanofluids from synthesis of metallic and nonmetallic nanofluids and hybrid nanofluids to the application of nanofluid. An exclusive review section on characterization techniques, improved and recent theoretical models for thermal conductivity, viscosity and specific heat developed by different researchers are presented and major applications areas of nanofluids are discussed in this review paper. Nanofluid is found to be a potential candidate for many applications. However, there are still many challenges that need to be overcome. These challenges include the long term stability of nanoparticle dispersions, increased pressure drop, pumping power requirements, nanofluid thermal performance in turbulent flow and in fully developed flow regions, higher viscosity, lower specific heat, thermal conductivity, high production cost, and difficulties in production processes. Especially, nanofluid stability and production costs are obstacles for the commercialization of nanofluids. A discussion on challenges of nanofluids is included in this review paper.

2. Preparation of nanofluids

Preparation of nanofluids is the first key step in experimental studies with nanofluids. Nanofluids are produced by dispersing nanometer-scale solid particles into base liquids such as water, ethylene glycol (EG), oils, etc. In synthesis of nanofluids, agglomeration is a major problem [9]. The delicate preparation of a nanofluid is important because nanofluids need special requirements such as an even suspension, stable suspension, low agglomeration of particles, and no chemical change of the fluid [10]. Xuan and Li [11] suggested methods used for stabilizing the suspensions: (i) changing the pH value of suspension, (ii) using surface activators and/or dispersants, (iii) using ultrasonic vibration. These methods can change the surface properties of the suspended particles and can be used to suppress the formation of particle clusters in order to obtain stable suspensions. The use of these techniques depends on the required application of the nanofluid. Selection of suitable activators and dispersants depends