International Communications in Heat and Mass Transfer 54 (2014) 115–125

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

A review on preparation methods and challenges of nanofluids☆

Nor Azwadi Che Sidik *, H.A. Mohammed, Omer A. Alawi, S. Samion

Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, UTM Skudai, 81310 Johor, Malaysia

ARTICLE INFO

Available online 26 March 2014

Keywords:
Preparation methods of nanofluids
Challenges of nanofluids

ABSTRACT

Nanofluid, as a kind of new engineering material consisting of nanometer-sized additives and base fluids, has attracted great attention from investigators for its superior thermal properties and many potential applications. In this review, we summarize the nanofluid preparation methods reported by different investigators in an attempt to find a suitable method for preparing stable nanofluids. Nanofluids are classified according to material type as metallic and nonmetallic nanoparticles since different nanoparticles need their own stability method. Various nanoparticle types with different basefluids are investigated. Moreover, challenges and future directions of applications of nanofluids have been reviewed and presented in this paper. The aim of this review is to summarize recent developments in research on the synthesis and characterization of stationary nanofluids and to try finding some challenging issues that need to be solved for future research.

Contents

☆ Communicated by W.J. Minkowycz.

* Corresponding author.
E-mail address: azwadi@fkm.utm.my (N.A.C. Sidik).

http://dx.doi.org/10.1016/j.icheatmasstransfer.2014.03.002

1. Introduction

Cooling is one of the most significant scientific challenges in the industrial area, which applies to many diverse productions, including microelectronics, transportation and manufacturing. Technological developments such as microelectronic devices operating at high speeds, higher-power engines, and brighter optical devices are driving increased thermal loads, requiring advances in cooling. The traditional method for increasing heat dissipation is to increase the area available for exchanging heat to use a better heat conductive fluid. However, this approach involves an undesirable increase in the size of a thermal management system; therefore, there is an urgent need for new and novel coolants with improved performance. The innovative concept of 'nanofluids' – heat transfer fluids consisting of suspended of nanoparticles – has been proposed as a prospect for these challenges [1].

A nanofluid is a fluid produced by the dispersion of metallic or non-metallic nanoparticles or nanofibers with a typical size of less than 100 nm in a liquid. Nanofluids have attracted huge interest lately because of their greatly enhanced thermal properties. For instance, experiments showed an increase for thermal conductivity by dispersion of a less than 1% volume fraction of Cu nanoparticles or carbon nanotubes in ethylene glycol or oil by 40% and 150%, respectively [1]. There are also various potential advantages from nanofluid testing namely: better long-term stability and thermal conductivity compared to millimeter or even micrometer sized particle suspensions and less pressure drop and erosion particularly in microchannels. Though, there are still major application prospects in advanced thermal applications, they remain in the early stages of development. About a decade ago, some researchers reported the heat transfer and flow characteristics of the different nanofluids, namely: Trisaksri and Wongwises [2], Beck [3], Wang and Mujumdar [4], Kakaç and Pramuanjaroenkij [5], Godson et al. [6], Li et al. [7] Wen et al. [8], and Leong et al. [9]. However, prior to use nanofluids for heat transfer, significant knowledge about their thermophysical properties is required, especially their thermal conductivity and viscosity. Many researchers have measured the thermophysical properties of nanofluids while many others used well-known predictive correlations. Their works have been both experimental and theoretical [10].

A few review papers have discussed on the preparation methods for nanofluids [11–13]. In the present paper, we attempt to review the preparation methods of nanofluids presented in previously published data with much more details. However, to the best of authors' knowledge, there is no comprehensive literature on the preparation and challenges of nanofluids. The purpose of this paper is to understand the lack stability of nanofluids, which is a key issue that influenced the nanofluid properties for application, and to propose suggestions that could lead one to prepare nanofluids stable over a long time, with negligible agglomeration and without chemical change of the fluid properties.

2. Preparation of nanofluids

The preparation of nanofluids is the key step in the use of nanoparticles to improve the thermal conductivity of fluids. Two kinds of methods have been employed in producing nanofluids. One is a single-step method and the other is a two-step method [14]. Nanoparticles, the additives of nanofluids, play an important role in changing the thermal transport properties of nanofluids. At present, various types of nanoparticles, such as metallic nanoparticles and ceramic nanoparticles, have been used in nanofluid preparation. In the following part, we will present the nanofluid preparation methods for eleven different nanoparticles reported in the literature.

2.1. Preparation of non-metallic nanofluids

2.1.1. Silicon dioxide-nanofluids

Silica is a widely used ceramic material both as a precursor to the fabrication of other ceramic products and as a material on its own. Silica has good abrasion resistance, electrical insulation and high thermal stability [15]. Timofeeva et al. [16] dispersed silicon dioxide nanopowders in non-polar organic fluid. Benzalkonium chloride, benzethonium chloride, and cetyltrimethyl ammonium bromide were tested as surfactants for dispersing silica. Surfactants were dispersed into the base fluid first, followed by introduction of the nanopowder. The mixture was homogenized by continuous stirring and sonicated 10 times (~80 W) for 5 min each time. Suspensions with 1 vol.% of SiO_2 nanoparticles with no surfactant and excess of each surfactant (5 wt.% or ~ 0.12–0.14 M) were prepared using the adsorption model with 'laying flat' and compacted 'standing up' layers of the surfactant molecules The visual appearance of suspensions 24 h after the last sonication was the best stabilizer for SiO_2/TH66, as shown in Fig. 1. Silica nanoparticles were functionalized using grafting silanes directly to the surface of silica nanoparticles by Yang and Liu [17]. A silane of (3-glycidoxylproyl) trimethyoxysilane was used for the functionalizing process. The mass ratio of the reacting silane and silica nanoparticles was taken as 0.115. The nanoparticles were dispersed into water and the solution was kept at the environmental temperature of 50 °C for 12 h. It was found that functionalized nanoparticles can still keep dispersing well after the nanofluid has been standing for 12 months even at the mass concentration of 10%. Moreover, no sedimentation was observed. They also prepared traditional nanofluid by dispersing and oscillating nanoparticles into water. Silica nanoparticle powders were firstly dispersed into deionized water and the suspension was then oscillated in an ultrasonic bath for 12 h. It was observed that sedimentation occurred after several days. Anoop et al. [18] dispersed an appropriate amount of SiO_2 nanoparticles in deionized water using an ultrasonic bath for 30 min. Further, this colloidal suspension was subjected to intensified ultrasonication by immersing a probe type sonicator in the nanofluids. Cyclic ultrasonic pulses for about 15 min were given to the suspension to achieve maximum possible de-agglomeration of particles. The pH value of the nanofluid suspension was kept away from the iso-electric pH value, at a magnitude of 4.5 by adding reagent grade nitric acid. It was observed that the nanofluids exhibited good stability over time. Fazeli et al. [19] dispersed SiO_2 nanoparticles in distilled water, and then the suspension was sonicated by an ultrasonic bath for at least 90 min. They found that silica nanofluids stayed stable for a period of 72 h without any visible settlement. Bolukbasi and Ciloglu [20] prepared SiO_2 nanofluids by using a magnetic stirrer. Then, the suspensions were transferred into an ultrasonic vibrator and sonicated continuously for 2 h (600 W and 40 kHz). They reported that no sedimentation was observed during

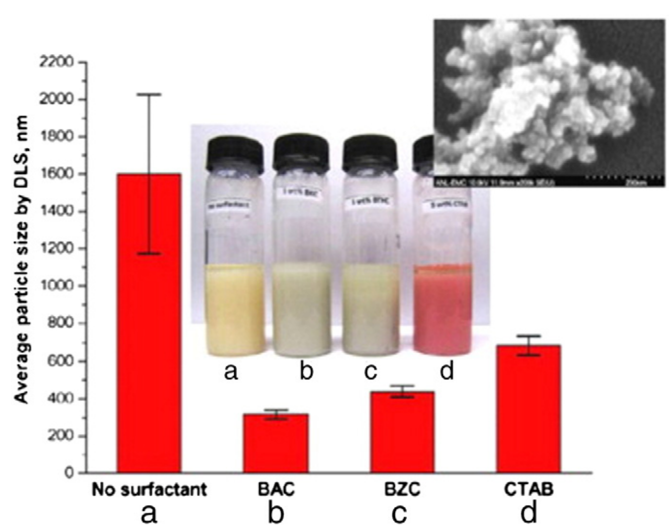

Fig. 1. Summary of DLS analysis of diluted SiO_2 dispersions in TH66 24 h after ultrasonication; (a) no surfactant, (b) benzalkonium chloride, (c) benzethonium chloride, (d) cetyltrimethyl ammonium bromide. (Inset, right) SEM image of SiO_2 powder used in preparation of nanofluids [16].