Renewable and Sustainable Energy Reviews 80 (2017) 1112–1122

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

A review on preparation methods, stability and applications of hybrid nanofluids

Nor Azwadi Che Sidik[a,*], Muhammad Mahmud Jamil[b], Wan Mohd Arif Aziz Japar[a], Isa Muhammad Adamu[a]

[a] Malaysia – Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia Kuala Lumpur, Jalan Sultan Yahya Petra (Jalan Semarak), 54100 Kuala Lumpur, Malaysia
[b] Department of Mechanical Engineering, Nigerian Defence Academy Kaduna, Nigeria

ARTICLE INFO

Keywords:
Hybrid nanofluid
Thermal conductivity
Stability
Preparation methods

ABSTRACT

Hybrid nanofluid is a new class of nanofluids engineered by dispersing two different nanoparticles into conventional heat transfer fluid. Hybrid nanofluids are potential fluids that offer better heat transfer performance and thermo-physical properties than convectional heat transfer fluids (oil, water and ethylene glycol) and nanofluids with single nanoparticles. Scientific findings have indicated that hybrid nanofluid can replace single nanofluid since it provides more heat transfer enhancement especially in the areas of automobile, electro-mechanical, manufacturing process, HVAC and solar energy. In this paper, we summarized the recent progress related to preparation methods of hybrid nanofluids, factors affecting their stability, methods of enhancing thermal properties and current applications of hybrid nanofluids. Finally, some challenging issues that need to be solved for future research are discussed.

1. Introduction

Thermal properties of heat transfer fluid (HTF) are a major area of research in heat transfer and fluid dynamics analysis. Cooling capabilities using conventional heat transfer fluid have been constrained because of the low thermal conductivity such as water, ethylene glycol and oil [1,2]. About two decades ago, nanofluid coined by Choi [3] has been proposed as the remedy to heat transfer enhancement. Nanofluid as an extension of nanotechnology, are fluids obtained by dispersing solid nanoparticles into base fluid [4–6]. One of the possible techniques for improving heat transfer is by adding millimeter- or micrometer-sized particles in fluids. Many published articles have reported significant improvement of heat transfer using nanofluid compared to conventional heat transfer fluid.

Hybrid nanofluid is a composition of two or more nanoparticles synthesis and dispersed in a base fluid. The advantage in heat transfer enhancement of hybrid nanofluid is due to its synergistic effect compared to nanofluid containing one nanoparticles. It is believed that, hybrid nanofluid could offer good thermal characteristics as compared to the base fluid and nanofluid containing single nanoparticles [7,8].

In 2007 Jana et al. [9] compared thermal conductivity enhancement of single and hybrid nano-additives. Interestingly, the result shows that the used of CNT-AuNP and CNT-CuNP hybrid nanofluid does not increase thermal conductivity compared to single nanofluid. After two years, In 2009 Jha et al. [10] performed similar research using hybrid of silver and multiwall carbon nanotube, thermal conductivity increased remarkably compared to the single nanofluids tested.

There are many parameters that highly contributed to the heat transfer enhancement of hybrid nanofluid such as base fluid selection, nanoparticles size, viscosity, fluid temperature and stability, dispersibility of the nanoparticles, purity of nanoparticles, preparation method, size and shape of nanoparticles and compatibility of the nanoparticles that leads to harmonious mixture of the nanofluid [2,11–15]. Among all the parameters, thermal conductivity is the key parameter that contributed immensely to heat transfer enhancement. Several researches have revealed significant enhancement of thermal conductivity using nanofluid [16–24]. Munkhbayar et al. [25], Suresh et al. [26], Aravind and Ramaprabhu [27], Chopkar et al. [28], and Chen et al. [29] observed a reasonable enhancement in thermal conductivity of hybrid nanofluid in comparison with base fluid and nanofluid containing single nanoparticles.

The findings of Abbasi et al. [30] shows that γ-Al_2O_3/MWCNTs hybrid gives thermal conductivity of 20.68% at volume fraction of 0.1%. In a similar research, the hybrid of Al_2O_3-Cu gives increase in

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

http://dx.doi.org/10.1016/j.rser.2017.05.221
Received 19 January 2016; Received in revised form 24 May 2017; Accepted 24 May 2017
Available online 02 August 2017
1364-0321/

thermal conductivity at volume concentration of 2% [31]. It was observed that both thermal conductivity and viscosity increased with increasing volume fraction. The convective heat transfer of fluid flow dominated by coefficient of convective heat transfer, also depends on thermal conductivity of the hybrid nanofluid. Due to small, inter atomic space that exist between the powders of metal nanoparticles results in higher thermal conductivity compared to other nanoparticles type [32]. The comparison between a hybrid mixture and single nanofluids resulted in thermal conductivity enhancement of the hybrid silica and multiwall carbon nanotube by 8.8% and 23.3% higher than the individual nanoparticles [33].

Using different experimental methods, Vafaei et al. [34] predicted the thermal conductivity of MgO-MWCNTs/EG hybrid nanofluid at volume fractions of 0.05–0.6% and temperature 25–50 °C. An optimal artificial neural network was used to predict the thermal conductivity with four neurons of 6,8,10 and 12 in hidden layers. The optimum neuron of 12 shows better result compared to other tested experiment. Recently, Vakili et al. [35] suggested a hybrid generic algorithm and artificial neural network as the best way in prediction of viscosity of graphene nanoplatelets. In a research conducted by Tessy et al. [36], hybrid nanostructure (f-MWNT+f-HEG) was synthesized by a post-mixing technique. The hybrid nanofluid was found to have 20% enhancement in thermal conductivity at volume fraction of 0.005%. The maximum enhancement of the heat transfer coefficient was about 289% for a 0.01% volume fraction of f-MWNT+f-HEG at Reynolds number of 15500.

Synthesis characteristics of hybrid Nano composite and magnetic-polymer were investigated by few researchers [37,38,39]. The primary objective of hybrid nanofluid research is to ensure it application in any equipment related to heat transfer. Turco et al. [40] conducted a broad experiments on the physiochemical properties of hybrid nanostructures for biotechnology application. In a similar study, hybrid Nano-polymer was prepared for the application in solar cell [41] and nanofluid for application in evacuated tube solar collector [42–44]. Moreover, the use of Al2O3-Cu/water hybrid nanofluid in heat sink for application in cooling electronics has demonstrated increased in convective heat transfer compared to water [45]. In another study, alumina-silver nanocomposite hybrid nanofluid was used in a helical heat exchanger to investigate the thermal performance and pressure drop. The hybrid nanofluid in this study showed higher percentage of heat transfer (31.58%) compared to the conventional heat transfer fluid (water) [46]. Conversely, another experimental result of Cu/TiO_2 hybrid nanocomposite/water applied in tubular heat exchanger revealed an increase in overall heat transfer of 30.4% at volume concentration of 0.7% [47]. With different nanoparticles of hybrid Al_2O_3/MWCNT, the hybrid nanofluid mixture was found to give highest pumping power in heat exchangers [48]. The influence of hybrid Al_2O_3 nanoparticle and micro encapsulated phase change material particles has shown a remarkable enhancement in terms of cooling effectiveness compared to single nanoparticles and water [49].

Baby et al. [50] considered hybrid nanofluid of hydrogen exfoliated graphene (HEG) and multi wall carbon nanotube (MWCNT) with convective heat transfer coefficient enhancement of around 570% at volume fraction of 0.005%. Differently, a numerical investigation of hybrid mixture of CuO-Cu nanoparticles shows that the heat transfer enhancement is dependent on increase in Reynolds number [51]. Convective heat transfer and effect of Nusselt number of hybrid Al_2O_3-Cu/water in circular tube has been explored by Suresh et al. [52]. The result revealed 13.56% enhancement of Nusselt number at Reynolds number of 1730. Moghadassi et al. [53] conducted a numerical study on heat transfer characteristics of Al_2O_3/Cu hybrid nanofluid. The simulated result shows that the Nusselt number and heat transfer coefficient increases with Reynolds number. The pressure drop and the friction factor coefficient increased with increase in volume concentration. Yen et al. [54] numerically investigated the effect of hybrid nanofluid in channel flows. Labib et al. [55] numerically studied the force convective heat transfer of CNT/ Al_2O_3 nanofluid, based on their study the convective heat transfer performance was observe to increase significantly. The increment was due to higher shear thinning behaviour of the CNT that causes thinner boundary layer.

In the literatures, there are a number of reviews on thermal characteristic and preparation of single nanofluids, however, there are very few reviews on preparation and thermal characteristics of hybrid nanofluids. Therefore, the aim of this paper is to give a further review on the recent progress on hybrid nanofluid in various engineering applications.

2. Hybrid nanofluid preparation methods

Synthesis of nanoparticle is the first step for obtaining a good hybrid nanofluid.

2.1. Preparation of hybrid nanofluid via solvo-thermal process

Pure MWCNT was functionalized by treating it with nitric acid. The nitric acid–MWCNT suspension was refluxed followed by stirring for 4 h. The suspension was ultra-sonicated in ultrasonic water bath for 4 h at 60 °C. The above sample is then washed in distilled water in order to obtain neutral pH and finally dried at 90 °C for 24 h. Aluminum acetate powder was dissolved in ethanol under vigorous stirring at room temperature for 30 min. The functionalized MWCNTs and pure MWCNT are then added to aluminum-ethanol suspension at room temperature with the aid of ultra-sonicator and then placed under vacuum (50cmHg) for 24 h. Ammonia solution was added slowly to the mixture to adjust the pH above 9 and thus obtain fine boehmite particles. The solution was then transferred to a 350 ml Teflon-lined stainless steel auto- clave chamber, where the solvothermal synthesis was conducted. 16 bar pressure was maintained in the autoclave for the synthesis and the solution was kept for 24 h at 200 °C. The autoclave was allowed to cool to room temperature and the collected precipitate was washed thoroughly with ethanol to obtain a neutral pH and then vacuum- dried at 60 °C for 6 h. The resulting powder is finally heated in argon atmosphere for 1 h at 500 °C. The hybrid nanofluid of γ-Al2O3/ MWCNTs is then finally obtained by dispersing the above hybrid nanopowder in deionized water which contain little amount of gum Arabic [30].

Graphene oxide flakes were dissolved in 100 ml of distilled water by ultra-sonication. $FeCl_3 \cdot 6H_2O$ and $FeCl_2 \cdot 4H_2O$ in a ratio of 1.75:1 were mixed with distilled water and the mixture was stirred with graphene oxide solution for 45 min sodium hydroxide was added in drop wise and a black precipitated was obtain. The precipitate was then washed with distilled water and finally freeze drying was done for 24 h to obtain GO-Fe_3O_4 hybrid [56].

Soluble nitrates of copper (Cu $(NO_3)_2 \cdot 3H_2O$) and aluminum, (Al $(NO_3)3.9H_2O$) were dissolved in water. The proportions of the above salts were decided to have a predefined relative proportion of alumina and copper oxide in the powder mixture. The solution was spray dried at 180 °C to obtain the precursor powder. The precursor powder was then heated at 900 °C in air atmosphere for 60 min to form a powder mixture of copper oxide and stable Al_2O_3. A tubular furnace was used to heat the mixture at 400 °C for 1 h in hydrogen atmosphere. The powder sample was then placed in an alumina boat and then kept in a horizontally placed alumina tube of the furnace, which was heated by silicon carbide heating elements. The CuO was preferentially reduced in hydrogen to metallic copper whereas Al_2O_3 remains unchanged. The powder mixture was finally ball milled at 400 rpm for 1 h. in order to obtain a homogeneous Al_2O_3-Cu nano-composite powder [26].

Hydrochloric acid and nitric acid in a molar ratio of 1:3 were mix with CNT with the aid of magnetic stirrer for 72 h at 60 °C. The above mixture was wash with distilled water and acetone, followed by oven drying at 80 °C for 24 h. This process gives rise to the formation of