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Heat transfer augmentation of ethylene glycol: Water nanofluids and applications — A review

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ABSTRACT

This paper introduces the historical background about the development of water based, ethylene glycol (EG) based and EG:water mixture nanofluids for the past 20 years. The primary consideration is to review the salient of research work related to EG:water mixture nanofluids and their applications. Nowadays, the fundamental studies of nanofluids are increasing rapidly for engineering applications. The determination of the forced convection heat transfer and pressure drop was reviewed for nanofluid flow in a tube. The experimental and numerical heat transfers of nanofluids were presented. A review of other relevant research studies is also provided. Substantial heat transfer literature has been studied on water based nanofluids used in the fundamental study for engineering applications. However, there are limited studies that use EG:water mixture nanofluids in evaluation of forced convection heat transfer. A number of research studies have been performed to investigate the transport properties of EG:water mixture nanofluids either in experimental or numerical approach. As the performance of EG:water mixture nanofluids could be verified through experimental studies, researchers have conducted the experimental works using several types of potential nanofluids. As a result, nanofluids have been used in certain engineering applications such as in automotive, transportation, cooling of electronics components, solar, and nuclear reactor coolant.

Contents

1. Introduction

Nanofluid is defined as the dispersion of nano-sized particle in a base fluid. Since the need for fluid that can enhance the efficiency of heat transfer equipment, nanofluid is introduced by Masuda et al. [1] where the experimental investigation concerned on thermal properties

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of the nanofluids. Compare to the ordinary heat transfer fluid such as water and oil, nanofluids are proved to exhibit superior heat transfer properties by the research conducted by Choi [2] and Eastman et al. [3]. With the study conducted by these researchers, nanofluid field later is expanding with investigations on many aspects related to the performance of the nanofluids.

Until today, there have been a lot of studies on heat transfer and the improvement is still developed especially in cooling capabilities. There is constraint in the development due to low thermal conductivity of the conventional heat transfer fluid. The thermal conductivity of solid particles is much higher than that of liquids. Therefore, it is expected that thermal conductivity of fluids that contain suspended solid particles could be significantly higher than that of conventional fluids. The theoretical and experimental studies of effective thermal conductivity of such liquids have been conducted earlier [4]. Hence, nanofluid is believed to have higher effective thermal conductivity than conventional fluids. The Maxwell's concept of enhancing the thermal conductivity of fluids by dispersion of solid particles is discovered many years before, however the innovative concept of nanofluid is the idea of using nanometer-sized particles to help it improve the rapid settling of particles in the fluid [5].

Nanofluids have been prepared using many types of materials. These include materials such as metal and non-metal, metal oxide, carbide, carbon nanotube (CNT), and hybrid. The dispersion of the nanoparticles is in various types of base fluid such as water, oil and glycols. The selection of the types of nanoparticles chosen depends on many reasons including the application of studies and performance. In the early period, metal or metal oxide types were used since the access to obtain the materials is easier where many manufacturers produce the materials. Zhu et al. [6] used copper dispersed in EG. The study emphasizes on using one-step method to prepare the nanofluids. For rheological behaviors, thermal conductivity and photo-thermal study, Meng et al. [7] used carbon nanoparticles in their study.

Another popular type of material used in nanofluid field is metal-oxide such as Aluminium Oxide (Al_2O_3), Copper Oxide (CuO) and Silicon Oxide (SiO_2). Ganguly et al. [8] studied on the effective electrical conductivity of nanofluid for dispersion of Al_2O_3 in water. For investigation on the convective heat transfer enhancement of nanofluids, Kulkarni et al. [9] used SiO_2 in mixture base fluid (water and EG). Meanwhile, Kole and Dey [10] used CuO in gear oil for their study on synthesis and measurement of nanofluid effective viscosity. In 2014, researchers such as Said et al. [11], Hajjar et al. [12], and Azmi et al. [13] used various types of metal-oxide nanofluids such as TiO_2, Al_2O_3, Graphene Oxide (GO) and SiO_2 in water dispersion. These studies were on the optical behavior of nanofluids, the effects of GO concentration and temperature on the thermal conductivity, and convective heat transfer of nanofluid under turbulent region, respectively.

For carbide type, Chun et al. [14] use Silicon Carbide (SiC) water based nanofluid for investigation on the effect of nanofluid on a boiling heat transfer of a thin platinum wire. Nikkam et al. [15] used α-SiC for study on the thermo-physical properties. Another carbon type material is carbon nanotube or well known as CNT was also used in nanofluid studies. The evaluation of photo-thermal properties, thermal conductivity and rheological behavior of nanofluids using CNT in EG based nanofluids was studied by Meng et al. [16]. An investigation of concentration and temperature effect to the thermo-physical properties of CNT nanofluids was performed by Halelfadl et al. [17]. For a new modification of CNT, Gao et al. [18] conducted a simulation investigation of nanofluid thermal properties and heat transfer interaction using functionalized CNT (FCNT) in water dispersion. While Hemmat Esfe et al. [19] used multi-walled CNT (MWCNT) for the study of thermo-physical properties, heat transfer and pressure drop of nanofluids.

The latest type of nanoparticles in the nanofluid study is hybrid nanoparticles. Two or more types of material are combined to produce the hybrid material using chemical process. Suresh et al. [20] used hybrid of Al_2O_3–Cu while Baghbanzadeh et al. [21] used spherical silica MWCNT for thermal conductivity and viscosity investigations. Madhesh et al. [22] used Cu–TiO_2 hybrid nanofluids. Sundar et al. [23] applied MWCNT-Fe_3O_4 for experimental research on convective heat transfer coefficient and friction factor in the turbulent flow for the heat transfer potential study. Both research used hybrid nanoparticles dispersed in water. Therefore, the main aim of this study is to give a comprehensive review on the research progress on the heat transfer augmentation of water and EG based nanofluids and their applications.

2. Water based nanofluids

Dittus and Boelter [24], Churchill and Usagi [25], Gnielinski [26] and Tam and Ghajar [27] developed correlations for the estimation of heat transfer coefficients of single-phase fluid flow in a circular tube under fully developed and transition flow conditions for constant heat flux boundary conditions. Experimental heat transfer coefficients and pressure drop with water based nanofluids were determined mostly under turbulent conditions of flow in a tube. The investigators have undertaken experiments at different operating conditions of concentration, material, particle size and temperature. Certain authors determined nanofluid properties while others used the values available in the literature to evaluate them. As reviewed by Azmi et al. [28], nanofluids provide enhancement in thermo-physical properties such as thermal conductivity and viscosity compared to traditional base fluids such as water and ethylene glycol. In another paper, Azmi et al. [29] present the new correlation for thermal conductivity and viscosity of water based nanofluids. Godson et al. [30] reviewed the enhancement of heat transfer with nanofluids.

Pak and Cho [31] estimated convective heat transfer coefficients in the turbulent Reynolds number range with Al_2O_3 and TiO_2 nanofluids dispersed in water and observed that the Nusselt number of the nanofluids increased with increasing volume fraction of the suspended nanoparticles and Reynolds number. Xuan and Li [32] estimated the convective heat transfer coefficient of the Cu nanofluid and found substantial heat transfer enhancement. Wen and Ding [33], Yang et al. [34] and Heris et al. [35] investigated the convective heat transfer of Al_2O_3 nanofluid in a circular tube under laminar flow conditions subjected to constant heat flux. They observed that the heat transfer rates increase with increasing concentrations of submicron particles to the base fluid. Heris et al. [36] conducted experiments in the laminar range with Al_2O_3 and CuO nanofluids and observed Al_2O_3 nanofluids to have higher heat transfer rates compared to CuO nanofluids. Most of the authors observed the heat transfer coefficients increase with nanofluid concentration. However, Pak and Cho [31] and Duangthongsuk and Wongwises [37] observed a decrease in heat transfer coefficients with certain nanofluids at certain concentrations and particle sizes. The reasons for the decrease in heat transfer coefficients have not been explained by these authors.

2.1. Experimental study

Preliminary experiments for the determination of thermo-physical properties and forced convection heat transfer coefficients with Al_2O_3 and TiO_2 submicron particles dispersed in water were done by Pak and Cho [31]. They conducted hydrodynamic and heat transfer experiments with nanofluids and obtained higher heat transfer coefficients which increased with concentration and Reynolds number. The nanofluid viscosity and thermal conductivity are observed to vary with volume concentration and temperature. However, the regression equation for the Nusselt number presented is independent of volume concentration. Xuan and Roetzel [38] proposed thermal dispersion as a major mechanism for heat transfer enhancement of a flowing nanofluid. Xuan and Li [32] conducted experiments with Cu/water nanofluid at different particle volume concentrations of up to 2%. At a Reynolds number of 20,000, the heat transfer coefficient containing 2% volume concentration of Cu nanoparticles was observed to be