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A review of thermophysical properties of water based composite nanofluids

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ABSTRACT

The limitation of the conventional fluids to facilitate cooling/heating rates remains the primary basis for exploring alternative heat transfer nanofluids. Research efforts on nanofluids have evolved over the past two decades in establishing extensive literature. Several models for thermophysical properties were made available to characterize the behaviors of diverse individual nanofluids. However, lack of reasonable agreement between theory and experimental results has been a limiting factor for the development of a unified nanofluid model for thermal conductivity. Existing models for thermo-physical properties of nanofluids such as density, specific heat, thermal conductivity, and viscosity are critically surveyed and appropriate equations are extended for composite nanofluids. Consequently, based on reliable models identified predictions for thermal conductivity and viscosity for composite nanofluids are presented. Overall results show that existing thermophysical models for density and specific heat are valid for all water based oxide nanofluids for both single material and composites whereas models for thermal conductivity and viscosity show selective response but have the versatility for predicting the behavior of single and composite nanofluids within acceptable deviation.

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1. Introduction

Modern advances in science and technology have invariably stimulated the emergence of various sophisticated equipment across various fields of human endeavor. For instance, in the electronic and automotive industries the demand for new thermal devices in tune with 21st century is characterized by their compactness with enhanced functionality. The design of devices is not devoid of challenges; a common aspect is the ability to remove high level of flux generated in the components. In order to improve the overall system performance, a number of salient concepts have been introduced. The use of extended surfaces and employment of solid additives in liquids are common methods for heat transfer augmentation. Regardless of all these practices, prior experiments to enhance the heat transfer with traditional liquids such as water, oil, and ethylene glycol are never materialized because of low thermal conductivity. Further experimental attempts with solid-liquid systems containing micro-sized particles also failed due to undesirable abrasion and clogging related problems [1–4]. With research efforts reinvigorated toward resolving the issue, Choi and Eastman [5] of the Argonne National Laboratory presented a new approach to improve the thermal conductivity of conventional fluids by dispersing particles of size smaller than 100 nm. The fluid/coolant prepared in this manner is termed as nanofluids. The nanofluids evolution now make development of efficient mechanical engines seem possible. Such machinery would be smaller, lighter, and cheaper as well as fuel efficient. Accordingly, the reduced tendency of nanofluids to sediment or clog flow channels and their ability to transport energy with limited penalty of pressure drop as compared to larger-sized particle suspensions is reported by various researchers. In fact, the plethora of literature presented over the past decade concerning the preparation, characterization [6–9] and thermo-physical properties [10–13] alone signifies the huge impact of nanofluids in changing various engineering processes.

One of the primary reasons for the escalating interest in nanofluid research can be ascribed to the development of innovative technologies for the manufacture of materials of nanometer size. This development has afforded scientists and engineers with powerful tools to produce materials with exceptional properties, superior than their bulk counterparts. Several materials are considered as possible options for heat transfer augmentation [14–17]. For example, metals (aluminum, copper, gold, iron, silver, etc), metal oxides (alumina, ceria, copper, magnetite, zinc, etc), semiconductors materials (silica, titania, tin, etc), metal nitride (aluminum nitride), metal carbide (silicon), carbon nanotubes (single-walled and multi-walled), graphene (multi-layer and oxide), etc. are used to enhance the thermal transport properties of working fluids. As highlighted in the literature [18,19], the choice of nanofluid for engineering application depends on their thermo-physical properties. For example, ethylene glycol tends to be a preferred base fluid in polar region due to its antifreeze properties. Thus ethylene glycol-water (EG-water) mixture is commonly used as a base fluid in cold climatic conditions [20,21]. Studies on nanofluids for various engineering application have been documented in review-papers [22–25].

So far nanofluids have demonstrated unbounded thermal management advantages with their unique and distinctive characteristics. Pertinent properties essential for fluid flow and heat transfer include the density, specific heat, surface tension, thermal conductivity, thermal expansion, and viscosity. However, the evaluation of these properties depends on underlying states of temperature, volume fraction, base fluid, pH, particle material, shape and size of the particles. Moreover, researchers have tried to establish theoretical and empirical property relationship in terms of these distinct parameters. A large number of investigators developed theoretical models for the estimation of viscosity and thermal conductivity of nanofluids. The models failed to validate the properties obtained through experiments. In contrast to the existing number of theoretical models for thermo-physical properties, empirical models are relatively few due to limited experimental data. It is noteworthy that a few attempts have been made to provide general empirical models applicable to nanofluids dispersed with spherical particles using experimental data [26,27]. Notwithstanding, engineers are far from achieving a versatile thermo-physical property model, one that is capable of accommodating all the fitting influential factors for the prediction of nanofluid properties precisely.

Nonetheless, several experimental works reported in the literature focused on thermophysical properties of nanofluids [28–36]. Extensive data relating to such properties have been presented through comprehensive reviews [37–44]. Mechanisms and models for thermo-physical properties are mainly elaborated in the reviews but less attention has been paid to carefully analyze the relevance of individual property models across various types of nanofluids. It is felt that in-depth literature sampling on property models could provide valuable information on the reliability of various equations for Single material Nano fluid (SmNf).

It is worth noting that certain thermo-physical properties models can be applied to validate experimental data which could eliminate the need to develop new individual models. Though, uncertainty is unavoidable in the measurements of nanofluid properties, the existing generalized models are developed from reliable data sources; hence, they would be expected to harmonize with relevant data for SmNf. Therefore, the present review seeks to present the state of knowledge based on several mechanisms affecting nanofluids and the thermo-physical models presented by the researchers over the three decades of intensive research contributions. Herein, the existing thermo-physical models are streamlined and compared with experimental data for water based SmNf.

2. Properties of single material nanofluids

The overall effectiveness of a heat transfer process depends on