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Review

Thermal conductivity of hybrid nanofluids: A critical review

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ABSTRACT

Innumerable studies are conducted on nanofluids containing single type nanoparticles and attributes of such colloidal mixture have been well elucidated and prospected. Furtherance in nano-composites has entitled production of hybrid nanomaterials (nanoparticles) and remarkable researchers are exploring hybrid nanofluid characteristics. The cardinal objective of this study is to provide a comprehensive review on thermal conductivity of hybrid nanofluids by overviewing experimental, numerical and ANN (artificial neural networking) studies. Assorted factors that affect thermal conductivity such as nanoparticle type, concentration of nanoparticles, types of base fluid, size of nanoparticle, temperature, addition of surfactant, pH variation and sonication time are analyzed in present paper. Additionally, synthesis of hybrid nano-composites, preparation of hybrid nanofluids, approaches for stability measurement and enhancement, methods of thermal conductivity measurement and reasons for thermal conductivity enhancement are discussed. Miscellaneous empirical correlations developed by researchers for thermal conductivity prediction of hybrid nanofluids are also compiled and presented. Results suggest that enhancing temperature and concentration increases thermal conductivity and proper selection of hybrid nanoparticles plays a prime role in attaining stability of hybrid nanofluids.

Contents

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Nomenclature

AD	average deviation
CNTs	carbon nanotubes
Conc.	concentration
DWCNT	double walled carbon nanotubes
DI water	deionized water
EG	ethylene glycol
FMWCNTs	functionalized multi walled carbon nanotubes
GO	graphene oxide
K	thermal conductivity
K_{nf}	thermal conductivity of nanofluid
K_{bf}	thermal conductivity of base fluid
K_r	ratio of thermal conductivity of nanofluid to base fluid
MWCNTs	multi walled carbon nanotubes
MD	maximum deviation
ND	nano-diamond
R	ratio of TiO_2 to SiO_2
SWCNTs	single walled carbon nanotubes
SD	standard deviation
T	temperature
VR	volume ratio
$\emptyset$	volume fraction

1. Introduction

Technological evolution intensified heat generation in many applications such as manufacturing, microelectronics, transportation and thermal power plants etc. requiring efficient coolants for proper heat dissipation. Generally active and passive methods [1–4] are adopted for heat rejection from these systems. Conventional coolants like water, ethylene glycol, propylene glycol and oils possess low thermal conductivity which is hindrance towards the path of improving system thermal efficiency. This led to development of novel coolants having high thermal conductivity. One of the possible routes to improve thermal conductivity of conventional coolants is addition of nano-sized particles in them. This mixture of nano-sized particles (nanoparticles) and coolants is known as nanofluid, which can dissipate more heat due to higher thermal conductivity resulting in improved thermal performance of system [5].

Frequently used nanoparticles include metals (Cu, Ag, Ni, Au), metal oxides (Al_2O_3, CuO, MgO, ZnO, SiO_2, Fe_2O_3, TiO_2), metal carbide (SiC), metal nitride (AlN) and carbon materials (CNTs, MWCNTs, diamond, graphite). The thermal conductivity of nanofluid is dependent on numerous factors such as type, shape, size and stability of dispersed nanoparticles, type of base fluid used, concentration of nanoparticles and fluid temperature [6–8]. In extensive engineering applications, nanofluids showed better performance than conventional fluids when used as heat transfer medium [9–18].

Further improvement in thermal conductivity of single nanoparticles can be achieved by hybridization of two or more different nanoparticles and these new composite nanoparticles prepared are known as hybrid nanoparticles. Different techniques to synthesize hybrid nanoparticle includes in-situ, mechanical alloying, thermo-chemical, ball milling, wet chemical, solvo thermal, chemical reduction, chemical vapor deposition, aerosol and many others. Turcu et al. [19] was likely to be the first to report synthesis of hybrid nanoparticles (MWCNTs/Fe_2O_3).

Hybrid nanofluids are extension of mono nanofluids and are obtained by dispersion of hybrid nanoparticles in the base fluid using single or two-step method. Two step method is most widely used by researchers because of cost effectiveness and their capability to be produce hybrid nanofluids at large scale. Various parameters like preparation method, size and shape of hybrid nano-composite, level of nanoparticles purity, dispersion capability of hybrid nanoparticles, compatibility among particles and

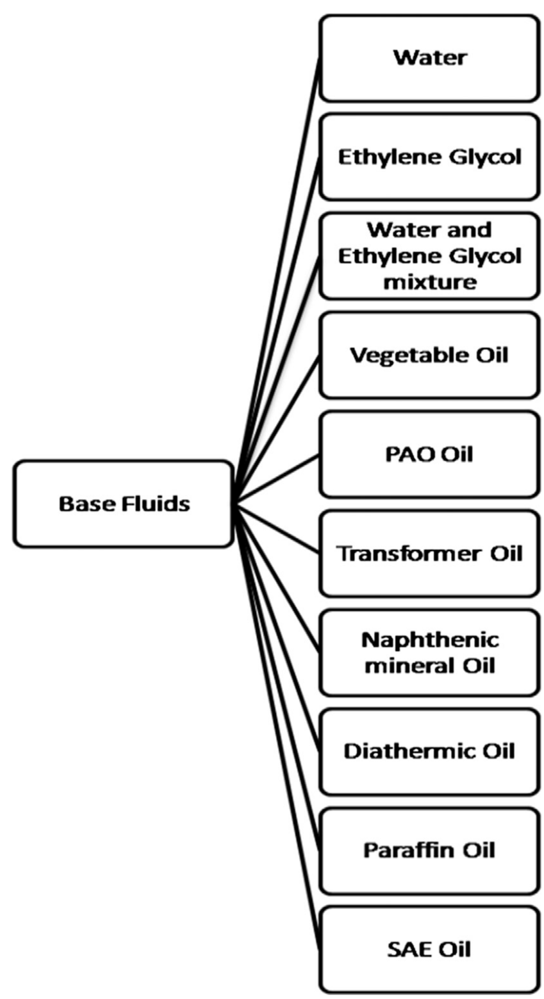

Fig. 1. Base fluids used by researches to prepare hybrid nanofluids.