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Review

Recent developments on viscosity and thermal conductivity of nanofluids

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ABSTRACT

The physical properties and especially viscosity and thermal conductivity are essential parameters for evaluating the heat transfer and flowing drag coefficients when designing a nanofluid system. This review presents a state of the art research progress of both the experimental and theoretical researches on viscosity and thermal conductivity of nanofluids. The results indicate that the viscosity and thermal conductivity of nanofluids are generally functions of particle loading, size, temperature and sometimes particle shape in their experimental range. Effect of material types is regularity on thermal conductivity but irregular on viscosity since the thermal conductivity of Graphene, CNTs, Au nanofluids is greatly higher than ordinary nanofluids but no orderliness could be found in viscosity for different particle types. Particle loading has a positive correlation with the relative viscosity and thermal conductivity but effects of particle size, shape, base fluid property and temperature are not unified. Although many influence factors have been considered, the main defect of the current modeling research is the failure of predicting the results in separate works due to the wide differences. Finally, the challenges and opportunities for the future studies are identified.

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Nomenclature

A, B, C	customization parameters in certain model
d	particle diameter, nm
e(u)	eccentricity of the ellipsoidal particle
g	empirical parameter in H-C model
H	height of finite length cylindrical particle, nm
k	thermal conductivity, $W\cdot(m\ K)^{-1}$
k_{11}^c	transverse equivalent thermal conductivity of the CNT
k_{33}^c	longitudinal equivalent thermal conductivity of the CNT
K_B	Boltzmann constant.
l	inter-particle distance, nm
L	length of CNTs, nm
n	empirical shape factor
R	radius of particle, nm
R_b	the interfacial thermal resistance between particle and liquid
t	thickness of interfacial layer, nm
T	temperature, K
V	velocity

Greek letters

α, β, γ	customization parameters in the present model
α_k	Kaptiza radius
γ_1	the thermal conductivity ratio of interfacial layer to particles
μ	viscosity
θ	the fraction of the liquid volume which travels with a particle
φ	volume fraction of nanoparticles, %
ρ	nanoparticle's density
ω	angle between the axial direction of the cylinder and the isotherm

Subscripts

B	Brownian motion
cl	clusters
eff	effective
f, bf	base fluid
lr	interfacial layer
m	maximum
p	particle (rod)
pe	equivalent
x, z	x-axis, z-axis

Abbreviations

CNT	carbon nanotube
CTAB	Cetyltrimethyl Ammonium Bromide
DIW	deionized water
DW	distilled water
MWCNT	multi-walled carbon nanotube
PG	propylene glycol
PAO	polyalphaolefin
SDBS	sodium dodecyl benzene sulfonate
SWCNT	single walled carbon nanotube

1. Introduction

Along with the development of nanotechnology, nanomaterials synthesized show tremendous potential in many aspects of engineering applications. Nanofluid is a novel outcome of nanotechnology applied in thermal fluid systems and it is of great potential for improving the system performance remarkably. It is expected to take the place of conventional media in energy-efficient heat transfer equipment due to its unique properties in thermal conductivity and viscosity [1]. The dispersed nanoparticles whose at least one-dimensional size is in the range of 1–100 nm (such as nanoparticle, nano-rod, nano-wire, nanotube) in nanofluid can bring an enhancement in thermal conductivity and viscosity compared with base fluid. Therefore, the physical properties including thermal conductivity and viscosity are essential parameters to investigate the great potential for heat transfer enhancement of flowing liquid.

There are mainly two methods for the preparation of nanofluids: one-step method and two-step method [2]. In one-step method, nanofluids are produced accompanying with the generation process of nanoparticles. One-step method mainly includes vapor deposition, laser ablation, submerged arc and chemical reduction method. Due to avoiding the drying and transporting and storage processes in one step method, the nanofluids in general have better dispersion stability. However, the required base fluid is generally not the solution of synthetizing nanoparticles especially for chemical reduction method which can easily bring by-products. Therefore, the widely used method of nanofluids for the energy and heat transfer application is two-step method. In two-step method, the preparation processes of nanoparticles and nanofluids are implemented independently. Dry nanoparticles are produced firstly and then suspended into the given kind of bulk fluid. However, the dispersing process of nanoparticles into liquid has a strong possibility of causing aggregating and colliding of particles due to the extremely high surface activity and interaction force of nanoparticles. Therefore, some dispersion techniques such as adding dispersant, sonication, adjusting the pH value are employed to improve the dispersion behavior of nanoparticles in base fluid.

Above dispersion techniques used in the preparation of nanofluids will affect the properties of nanofluids and make it harder to control according to the needs and understand the influence mechanisms. Thermal conductivity enhancement is the primary excepted benefit of nanofluids when applied as thermal working fluid. Numerous experimental and theoretical researches have exhibited the thermal conductivity enhancement and the various influence factors on it. The types of nanofluids have greatly developed and expanded in the past several decades. The overwhelming majority of current thermal conductivity models of nanofluids have contained the influence of particle's type viz. thermal conductivity of particle. Besides, other factors such as particle/aggregation size [3–5], shape [6–8] and structure [9,10], fluid type [11–13], pH value [14–16], surfactant [14] and temperature [17–20], etc. were also widely investigated by experimental and theoretical means. Simultaneously, a large number of theoretical investigations and calculation models on the thermal conductivity of nanofluids have been proposed by considering those specific influence factors.

Viscosity is likewise a very important property that determines the flowing skin friction coefficient [21], pressure drop and pumping power in a thermal system. Also the influence of viscosity on the velocity of the nanofluid will change the temperature distribution and hence affects heat transfer characteristic [22]. Therefore, the viscosity should be determined by experimental or numerical means before design a heat transfer system with nanofluids as the working fluid. Similar to thermal conductivity, many parameters such as particle concentration, size and shape, temperature, pH value and surfactant have been studied by various scholars. This paper reviews the latest experimental and modeling studies conducted on the viscosity and thermal conductivity of nanofluids via considering various the above mentioned parameters.