International Journal of Heat and Mass Transfer 117 (2018) 474–486

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Heat transfer efficiency of Al_2O_3-MWCNT/thermal oil hybrid nanofluid as a cooling fluid in thermal and energy management applications: An experimental and theoretical investigation

Amin Asadi [a,*], Meisam Asadi [b], Alireza Rezaniakolaei [a,*], Lasse Aistrup Rosendahl [a], Masoud Afrand [c], Somchai Wongwises [d]

[a] Department of Energy Technology, Aalborg University, Pontoppidanstraede 111, DK-9220 Aalborg, Denmark
[b] Young Researchers and Elite Club, Semnan Branch, Islamic Azad University, Semnan, Iran
[c] Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[d] Fluid Mechanics, Thermal Engineering and Multiphase Flow Research Lab. (FUTURE), Department of Mechanical Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi, Bangmod, Bangkok, Thailand

ARTICLE INFO

Article history:
Received 15 August 2017
Received in revised form 3 October 2017
Accepted 9 October 2017

Keywords:
Experimental study
Heat transfer efficiency
Thermophysical properties
Convection heat transfer coefficient
MWCNT and Al_2O_3 nanoparticles

ABSTRACT

The main objective of the present study is to assess the heat transfer efficiency of Al_2O_3-MWCNT/thermal oil hybrid nanofluid over different temperatures (25–50 °C) and solid concentrations (0.125%–1.5%). To this end, first of all, the stability of the nano-oil has been studied through the Zeta potential analysis. Then, the dynamic viscosity and thermal conductivity of the nanofluid have been experimentally investigated. It was found that the nanofluid showed Newtonian behavior over the studied range of temperatures and solid concentrations. The dynamic viscosity showed increasing trend as the solid concentration increased. It is found that the minimum increase in dynamic viscosity is at the temperature of 50 °C in all the studied solid concentrations except 0.5% and 1%. As for the thermal conductivity, it showed increasing trend as the temperature and solid concentration increased. The maximum enhancement was at the temperature of 50 °C and solid concentration 1.5% by approximately 45%. Based on the experimental data, two new highly precise correlations to predict the dynamic viscosity and thermal conductivity of the studied nanofluid have been proposed. Moreover, the heat transfer efficiency of the nanofluid has been evaluated based on different figures of merit. It is revealed that using this nanofluid instead of the base fluid can be beneficial in all the studied solid concentrations and temperatures for both the internal laminar and turbulent flow regimes except the solid concentrations of 1 and 1.5% in internal turbulent flow regimes. The effect of adding nanoparticles on pumping power and convective heat transfer coefficient has also been theoretically investigated.

1. Introduction

Thermal oils have been widely used as a coolant fluid for heat transfer and energy management applications in various industries such as automotive and electrical industry. Furthermore, thermal oils are the dominant fluids in the applications of lubricating and cooling the internal combustion engines. The most important functions of engine oils can be summarized as: lubricating the engine parts in both the low and high temperatures, reducing the wear on different moving parts, cooling down the engines by carrying heat away from moving segments, protecting the emission systems, and so forth. To this end, viscosity and thermal conductivity of oils play an important role. In other words, lower viscosity results in lower pumping power and pressure drop and on the other hand, higher thermal conductivity means higher heat transfer performance.

Nanofluids are a suspension of nanoparticles in conventional working fluids such as water, ethylene glycol, and motor oils, which are introduced for the first time by Choi [1]. Adding the particles which have higher thermal conductivity compared to that of the base fluids results in improving the thermophysical properties of the working fluids. This feature grabs the attention of many researchers in recent decade to utilize the invaluable characteristics of this new class of working fluids in different applications [2–14].

* Corresponding authors.
E-mail addresses: Ams@et.aau.dk, Aminasadi64@gmail.com (A. Asadi), Alr@et.aau.dk (A. Rezaniakolaei).

https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.036
0017-9310/

Nomenclature

K	Thermal conductivity
C_p	Specific heat capacity
Nu	Nusselt number
D	Hydraulic diameter
h	Convective heat transfer coefficient
Mo	Mouromtseff number
W	Pumping power
φ	Nanoparticles volume fraction
Greeks	
ρ	Density
τ	Shear stress
γ	Shear strain
μ	Dynamic viscosity
Subscripts	
bf	Base fluid
nf	Nanofluid
p	Particle

Since the thermophysical properties of thermal oils are crucial, researchers tried to improve them by adding different nanoparticles, oxide and non-oxide particles and carbon nanotubes, to engine oils. One of the most important factor is the viscosity of thermal oils. In this regard, there are limited numbers of published paper by researchers [15–17]. For instance, the rheological properties of oil-based nanofluid containing multi-wall carbon nanotubes (MWCNT) and SiO_2 nanoparticles have been experimentally investigated by Hemmat et al. [18]. Their results revealed that the studied nanofluid is a Newtonian fluid and its dynamic viscosity showed increasing trend as the solid concentration of the particles increased. Asadi and Asadi [19] investigated the viscosity behavior of ZnO-MWCNT/oil hybrid nanofluid over different temperatures and solid concentrations. They indicated that the produced nano-oil showed Newtonian behavior over the studied range of shear rates, temperatures and solid concentrations. Furthermore, they proposed a new correlation to predict the dynamic viscosity of the nanofluid. In another experimental study, the dynamic viscosity of the Al_2O_3-engine oil nanofluid has been investigated over different range of temperatures and solid concentrations, by Hemmat et al. [20]. Their results revealed that the produced nanofluid is a Newtonian fluid and its dynamic viscosity increases as the solid concentration increased. The maximum increase was about 132% compared to that of the pure oil. In another investigation done by Hemmat et al. [21], the viscosity of the Non-Newtonian engine oil-based nanofluid containing TiO_2 particles has been studied over different temperatures (ranging from 25 °C to 50 °C) and solid concentrations (ranging from 0.125% to 1.5%). They proposed a new correlation to predict the dynamic viscosity of the nanofluid. They also reported that the viscosity of the nanofluid is more sensitive to variations of solid concentration. Asadi et al. [22] studied the viscosity of motor oil-based nanofluid containing magnesium oxide particles. They observed that the nanofluid is a Newtonian fluid and its viscosity increases as the solid concentration increased while it decreases as the temperature increased.

Thermal conductivity is another important factor in selecting a proper thermal oil. Despite the fact that the thermal conductivity of different nanofluids has been comprehensively investigated by many researchers [23–33], thermal conductivity of the oil-based nanofluids has not been widely and comprehensively studied so far [34–37]. The thermal conductivity of MWCNT nano-oil has been experimentally studied at the temperature of 20 °C by Ettefaghi et al. [38]. They conducted the experiments over a limited range of solid concentrations (ranging from 0.1 to 0.5 wt%) and they found that the thermal conductivity of the base fluid increased as the solid concentration increased. The maximum enhancement was about 23% at the solid concentration of 0.5 wt%. Aberoumand and Jafarimoghaddam [39] studied the thermal behavior of Cu-engine oil nanofluid in a limited range of solid concentrations (ranging from 0.5% to 1%) and wide range of temperatures (ranging from 313 K to 380 K). They reported the maximum enhancement of 31% in thermal conductivity of the nanofluid at the solid concentration of 1 wt% and temperature of 380 K. In another experimental investigation done by Aberoumand et al. [40], the thermal conductivity of nano-oil containing silver particles has been empirically studied. They reported that the thermal conductivity of the nanofluid showed increasing trend as the solid concentration and temperature increased. Furthermore, they proposed a new correlation to predict the thermal conductivity of the nanofluid in the studied range of temperatures and solid concentrations.

From the literature review presented above, it can be concluded that thermophysical and rheological properties of engine oils play an important role in the performance of oil. Although researchers conducted some studies on these parameters, there is yet a large gap to fill in rheological properties of the nano-oils. On the other hand, there is no study on the heat transfer efficiency of the nano-oils with respect to the enhancement ratio of dynamic viscosity and thermal conductivity. In the present investigation, the dynamic viscosity and thermal conductivity of Al_2O_3-MWCNT/engine oil hybrid nanofluid has been studied over the different range of temperatures and solid concentrations. Two new correlations to predict the dynamic viscosity and thermal conductivity have been proposed in terms of temperature and solid concentration. Furthermore, based on different figures of merit, the heat transfer capability of the nanofluid has been evaluated in both the internal laminar and turbulent flow regimes. Finally, the effect of adding nanoparticles on convection heat transfer coefficient and pumping power has been theoretically investigated.

2. Materials and methods

2.1. Nanofluid preparation

Two-step method, which is a widely used method by different researchers [41–43], has been applied to prepared the Al_2O_3-MWCNT (85-15)/oil hybrid nanofluid in six different solid

Table 1
Characteristics of the studied nanoparticles.

	MWCNT	Al_2O_3
Purity	>97%	99+ %
Size (nm)	Outside diameter: 20–30 Inside diameter: 5–10 Length: 10–30	20
Color	Black	White
Specific surface area (SSA) (m^2/g)	110	138
Specific heat capacity (kJ/kg K)	0.71	0.88
Density (kg/m^3)	0.0021	3890
Thermal conductivity (W/m K)	1500	36