Energy Conversion and Management 175 (2018) 1–10

Contents lists available at ScienceDirect

Energy Conversion and Management

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

A guideline towards easing the decision-making process in selecting an effective nanofluid as a heat transfer fluid

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ARTICLE INFO

Keywords:
Heat transfer effectiveness
Thermal conductivity
MWCNT-ZnO nanoparticles
Oil-based nanofluid
Pumping power
Microchannel

ABSTRACT

The present research aims to suggest a three-step guideline towards selecting a proper Nanofluid regarding the heat transfer effectiveness. To do so, employing two-step technique, the nanofluid's samples were prepared in various nanoparticles' concentrations (0.125, 0.25, 0.5, 0.75, and 1%) of MWCNT-ZnO hybrid nanoparticle in a thermal oil. The samples' stability has been examined employing the Zeta potential analysis. The samples' thermal conductivity has been experimentally measured at various temperatures (15, 25, 35, 45, and 55 °C) and solid concentrations. After that, a three-step guideline to select a proper nanofluid as a heat transfer fluid has been proposed. Then, for both the internal laminar and turbulent regimes, variations of pumping power due to adding hybrid nanoparticle has been theoretically studied. Furthermore, the possible effects of adding nanoparticles on the convective heat transfer coefficient in a microchannel heat sink have been investigated. The results declared that the convective heat transfer coefficient had been enhanced by 42%. It is concluded that the produced nanofluid, as coolant fluid, would bring a certain benefit in heat transfer applications. These pre-assessment process would ease the decision-making process in selecting a new coolant which possesses superior heat transfer properties in comparison to the conventional coolants (i.e., water and oil).

1. Introduction

Undoubtedly, thermal oils are a promising heat transfer fluid in High-temperature applications; for instance, electronic cooling, automotive, aerospace, solar collectors, combustion engines, and marine or military applications. Moreover, thermal oils are capable of being employed in low-pressure heat transfer systems to achieve high temperatures. Apart from that, thermal oils are the dominant lubricant and coolant fluid with the main responsibilities of reducing the friction between different moving components, cooling down the moving parts, as well as sealing and cleaning different parts of engines.

After the introduction of nanofluids by Choi [1], which are a suspension of nanoparticles in different base fluids (i.e., water, ethylene glycol, oils, etc.), new doors to having coolant fluid with superior thermophysical properties have been opened. After this pioneering study by Choi [1], many researchers conducted various projects to investigate the thermal conductivity variations [2–6], dynamic viscosity [7], and heat transfer and thermal performance [8,9] of different nanofluids in various applications such as solar power and solar collectors [10–12], fuel cells [13,14], and solar stills [15,16].

It is known that, in heat transfer applications, the convective thermal effectiveness of the coolant fluid is of paramount importance. This factor crucially relies on the effective thermophysical properties of the coolant fluid (i.e., thermal conductivity), which shows the heat transfer effectiveness of the coolant, specific heat transfer capacity, which determines the capability of the coolant to store and move the heat away from the hot source, and viscosity of the coolant, which affects the pumping power and the pressure loss of the cooling systems. Thus having a thermal oil with superior thermal conductivity and lower viscosity is quite desirable in heat transfer applications. In this ground, a limited number of projects have been conducted on the dynamic viscosity of different thermal oils thus far. A summary of these investigations is presented in Table 1. Generally, the literature on the dynamic viscosity of the thermal oil-based nanofluids declared that the dynamic viscosity shows increasing trend as the solid concentration of nanoparticles increases while it shows a decreasing trend by increasing the temperature of the nanofluid.

As for the thermal conductivity, which is another important parameter in selecting a coolant fluid, Aberoumand and Jafarimoghaddam [25] investigated the thermal conductivity behavior of Cu-silver thermal oil-based nanofluid at different temperatures and solid concentrations. They declared that the thermal conductivity enhanced by 49% as the temperature and solid concentration increases. They also presented a new correlation to estimate the thermal conductivity of the nanofluid. In another research, Eteffaghi et al. [26] experimentally studied the thermal conductivity of MWCNT/thermal oil-based

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https://doi.org/10.1016/j.enconman.2018.08.101
Received 12 June 2018; Received in revised form 12 August 2018; Accepted 27 August 2018
0196-8904/

Nomenclature

K	thermal conductivity (W/m °C)
C_p	specific heat capacity (kJ/kg K)
Mo	Mouromtseff number
W	pumping power
Nu	Nusselt number
h	convective heat transfer coefficient
D_h	hydraulic diameter
W_{ch}	width of the channel
H_{ch}	Height of the channel
L_{ch}	length of the channel

Subscripts

bf	base fluid
nf	nanofluid
p	nanoparticle
ch	channel

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φ	nanoparticles volume fraction
ρ	density (g/cm^3)
μ	dynamic viscosity (cP)
α	aspect ratio

nanofluid over different solid concentrations (from 0.1 to 0.5 wt%) and at the T = 20 °C. They reported that the thermal conductivity of the studied nanofluid had been enhanced by 22.7%. The thermal conductivity of a thermal oil-based nanofluid containing Ag nanoparticle was experimentally investigated by Aberoumand et al. [27]. They declared increasing the temperature and solid concentration results in increasing the thermal conductivity.

It is common knowledge that adding nano-sized particles that possess different thermal properties compared to conventional coolant fluids (i.e., water, ethylene glycol, oils, etc.) affect the thermophysical properties of the resultant fluid. The literature showed that, for instance, the thermal conductivity of the resultant fluid (nanofluid) is greatly enhanced while the specific heat (c_p) adversely decreased in comparison to that of the base fluid. As for the viscosity, adding nanoparticles to the base fluid considerably increase the dynamic viscosity of the new fluid, which causes the increase in pumping power and pressure loss. Thus, it is crystal clear that changing the thermophysical and rheological properties of a coolant fluid results in changing the heat transfer performance of the new fluid under different flow regimes; laminar and turbulent. In this regards, there are limited numbers of literature investigating the heat transfer performance of various nanofluids, especially thermal oil-based nanofluids, based on different figures-of-merit before using them in real heat transfer applications. Asadi et al. [28] studied the heat transfer effectiveness and pumping power of an oil-based hybrid nanofluid containing Al_2O_3 (85%) and MWCNT (15%) in different temperatures (20–50 °C) and solid concentrations (0.125–1.5%). Their results showed that using the studied nanofluids in heat transfer applications would bring a certain advantage in all the studied temperatures and solid concentrations other than the solid concentrations of 1% and 1.5%. On the contrary, in another study, the thermal performance as well as the pumping power of graphene nanoplatelets suspended in a binary working fluid (EG-water) have been studied by Cabaleiro et al. [29], and their results showed that employing the studied nanofluid would not bring any benefits in heat transfer applications. Quiet the recently, Asadi et al. [30] investigated the heat transfer performance as well as pumping power of MgO-MWCNT/thermal oil-based hybrid nanofluid in different flow regimes (laminar and turbulent). Their results declared that although using the prepared nanofluid causes some penalty in pumping power, the nanofluid possess the excellent capability to be employed as a coolant fluid in practical heat transfer applications. Table 2 presents a summary of the previously published papers on heat transfer performance of different nanofluids based on some figures-of-merit.

From what has been discussed thus far and based on the available literature, it is evident that the thermophysical properties of the conventional coolant fluids are enhanced by adding nano-sized particles. However, it also has negative impacts on some of the properties such as increasing the dynamic viscosity and decreasing the specific heat capacity of the base fluid. Thus studying the heat transfer performance of the new fluid is of paramount importance to determine the heat transfer capability. The present investigation is the continuation of the author's previous study on the dynamic viscosity variation of the thermal-based hybrid nanofluid containing ZnO and MWCNT nanoparticles [35]. It is tried to propose a guideline towards selecting a proper coolant for heat transfer applications. First of all, the thermal conductivity behavior of the hybrid nanofluid is experimentally measured at the temperatures ranging from 15 °C to 55 °C and solid concentrations ranging from 0.125% to 1%. According to the experimental results, a new correlation to estimate the thermal conductivity of the nanofluid is proposed. Then, based on different figures-of-merit, the heat transfer performance as well as pumping power of the nanofluid has been studied in both the internal laminar and turbulent flow regimes. Moreover, the effect of adding hybrid nanoparticles on the convective heat transfer coefficient of the nanofluid in a microchannel heat sink under constant heat flux boundary condition is theoretically scrutinized. The results of the present study would ease the decision-making process of selecting a new coolant fluid for heat transfer applications based on energy management point of view.

2. Nanofluid preparation and characterization

In the present study, it is tried to prepare the samples of nanofluids following the same procedure as Asadi and Asadi [19] applied in their investigation on the dynamic viscosity of the same nanofluid. Thus employing the two-step method, the MWCNT, and ZnO nanoparticles with the ratio of 15% and 85%, respectively, have been added to the base fluid (four seasonal engine oil 10W40) in five solid concentrations; 0.125, 0.25, 0.5, 0.75, and 1%. The required amount of the nanoparticles for each solid concentration has been determined using the following equation [3]:

$$\varphi = \left[\frac{(m/\rho)_{ZnO} + (m/\rho)_{MWCNTs}}{(m/\rho)_{ZnO} + (m/\rho)_{MWCNTs} + (m/\rho)_{Oil}}\right] \times 100 \tag{1}$$

where φ, m, and ρ represent the solid concentration of nanoparticles (%), the mass (kg), and density (kg/m^3), respectively.

It must be noted that the size of ZnO and MWCNT nanoparticles are 20–30 and 10–20 nm, respectively, which both of them have been purchased from the US research nanomaterials Inc. (the advanced nanomaterial provider). Fig. 1 shows the TEM images of the nanomaterials provided by the supplier. Then a mechanical stirrer has been employed for two hours to mix the nanoparticles into the base fluid. After that, to break down the possible agglomeration of the nanoparticles into the base fluid and to achieve a superb suspension, the mixed samples have been subjected to an ultrasonic processor (20 kHz, 1200 W) for one hour. The effect of using the ultrasonic processor to break down the agglomeration of the nanoparticles into the base fluid has been widely proofed by researchers [36,37]. In this way, it is expected to have a long-time stable nanofluid for at least ten days.

There is no doubt that the sedimentation and agglomeration of the nanoparticles are among the most important challenges and barriers on