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Thermophysical Properties of MWCNT -thermal oil NANO fluid for industrial Applications

Supreeti Das
Department of Physics, Gargi College, University of Delhi, India

Abstract
Thermophysical properties of (multiwalled carbon nanotube) mwcnt - thermal oil have been investigated for designing efficient heat removing medium for industrial applications. They have been evaluated for a range of concentrations using the effective medium theory. This theory derives the thermophysical properties of nanofluids by considering the properties of the base fluid and the solid which is an additive. As industrial applications entail varying temperatures, thus in the present study, temperature dependence of thermophysical properties of the base fluid has been introduced with empirical correlations from literature. These have been employed for the determination of the density, thermal conductivity, viscosity and specific heat capacity of the nanofluid, theoretically. While addition of mwcnt to thermal oil increases its density and thermal conductivity, the specific heat capacity decreases with the presence of mwcnt in thermal oil. Addition of mwcnt, increases the viscosity, however due to low concentration of mwcnt (0.05%-0.5% volume concentration), the increase in viscosity is low and hence there will be a negligible increase in the pumping costs in the industries.
Keywords: *Nanofluid, mwcnt, heat transfer, thermal oil*

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I. INTRODUCTION

Miniaturization in the electronic industries has resulted in high heat generation. For maintaining the performance and reliability of devices, innovative cooling techniques are now needed [31] which can remove the high heat efficiently [29,30,34,37] and maintain the temperatures [10,16,19]. Designing efficient thermal fluids for heat removal using novel materials is the latest challenge for automobile [23] industries. Efficient removal of heat decreases the size, cost and also can reduce the associated power consumption [7,22]. Adding solid particles of metals and metal oxides to the conventional heat removing fluid [9] was an ancient method of enhancing thermal conductivity. However, the experimental observations were that the particles clogged the channels, corroded the walls resulting in fast wear and tear of the walls. Heavier particles dispersed in the base fluid, had the problem of sedimentation too. Addition of solid particles resulted in the increase of viscosity of the medium increasing the requirement of higher pumping power. In the present paper thermal oil has been used as the base fluid [6], which is an important heat removing medium and is employed by engineers for thermal management in automobile industry for engine cooling. The significance of investigating the heat transfer characteristics of thermal oil originates from the fact it is also used in transformers as electric insulation liquid and for removing the excess heat that is generated in the system [2]. In particular for the functioning and for longer life of the transformers that are employed in grids for electricity distribution, it is very important to maintain the appropriate temperature of the oil. This can be possible by efficiently removing the heat generated. Motivated by the work of experimentalists [6,24,38] of adding smaller dimensional particles to the base fluid for heat transfer enhancement, mwcnt has been dispersed in thermal oil[3,4]. Unlike most nanoparticles, mwcnt is cylindrical and has a large surface area which is an important factor in heat transfer processes [9,10]. Due to the high thermal conductivity of mwcnt [36], enhancements in thermal conductivity have been reported experimentally with very low volume fractions[7,18]. Low concentration result in less agglomeration and more homogenous dispersion. The advantages of using mwcnt therefore is that the viscosity [12] does not increase appreciably resulting in minimal increase in pumping costs. Secondly, stable nano oil can be prepared without the addition of chemicals and surfactants which could potentially alter the thermophysical properties [5,8]. Ultrasonication, a mechanical method can be employed for uniform dispersion avoiding the sedimentation and the aggregation of the solid particles. For applications of nanofluids as heat transfer medium, the most important step is the investigation of thermophysical properties. In the current work, thermophysical properties of nano-oil is discussed using the correlations of the effective medium theory. These properties are compared with the correlations derived from the empirical results [16,19-22]. The general focus has been thermal conductivity in most of the earlier studies [18]. However, for industrial applications, evaluation of viscosity and specific heat at high temperatures is an essential study. As the concentration of mwcnt is small, the nanofluid is considered as single -phase fluid [17]. Simulating with various concentrations and within a range of temperatures is an essential step towards designing efficient nanofluids as a heat transfer medium. This reduces the wastage of chemicals resulting in reduction of cost as well water pollution caused by these testing chemicals. Secondly thermophysical properties variation with concentration and temperature facilitates the final choice of the nanoparticles to be used as additives for high temperature industrial thermal management.

Nomenclature

ρ_s density of solid $[kg/m^3]$
ρ_f density of base fluid $[kg/m^3]$
f volume fraction
β_s coefficient of volume expansion of solid $[1/K]$
β_f coefficient of volume expansion of base fluid $[1/K]$
β_{nf} coefficient of volume expansion of nanofluid $[1/K]$
c_s specific heat capacity of solid $\left[\frac{J}{kg\ K}\right]$
c_f specific heat capacity of base fluid $\left[\frac{J}{kg\ K}\right]$
c_{nf} specific heat capacity of nanofluid $\left[\frac{J}{kg\ K}\right]$
k_s thermal conductivity of solid $[W/mK]$
k_f thermal conductivity of base fluid $[W/mK]$
k_{nf} thermal conductivity of nanofluid $[W/mK]$
μ_f dynamic viscosity of base fluid $[Pa\ s]$
μ_{nf} dynamic viscosity of nanofluid $[Pa\ s]$

II. DESCRIPTION OF THE PROBLEM

For applications of nanofluids as heat transfer medium, the most important step is the investigation of thermophysical properties [11,14,]. In the current work, thermophysical properties of nano-oil [34,35]is discussed using the correlations of the effective medium theory (eqns. 1-5) [8,13]. These properties are compared with the correlations derived from the empirical results. Since the industrial applications involve high temperatures, thus the thermophysical properties have been studied both as functions of particle concentration [1,15] and temperature [20,23]. The general focus has been thermal conductivity in most of the earlier works [25-28]. However, for industrial applications, evaluation of viscosity and specific heat at high temperatures is an essential study [24]. As the concentration of mwcnt is small, the nanofluid is considered as single -phase fluid [32].

III. Governing equations

$$\rho_{nf} = (1-f) * \rho_f + f * \rho_s \tag{1}$$

$$\beta_{nf} = \frac{(1-f)*\rho_f*\beta_f+f*\rho_s*\beta_s}{\rho_{nf}} \tag{2}$$

$$c_{nf} = ((1-f) * \rho_f * c_f + f * \rho_s * c_s) / \rho_{nf} \tag{3}$$

$$k_{nf} = k_f * (k_s + 2 * k_f - 2 * f * (k_f - k_s)) / (k_s + 2 * k_f + f * (k_f - k_s)) \tag{4}$$

$$\mu_{nf} = \mu_f * (1 + 2.5 * f) \tag{5}$$

Table 1. Properties of MWCNT

Density(kg/m^3)	Thermal Conductivity(W/mK)	Specific heat$\left(\frac{J}{kg\ K}\right)$
2100	2000	733

Table 2. Properties of Thermal Oil

Density(kg/m^3)	Thermal Conductivity(W/mK)	Specific heat$\left(\frac{J}{kg\ K}\right)$	Viscosity$(Pa\ s)$
848	0.163	1950	0.0135(320K)

IV. RESULT and DISCUSSION

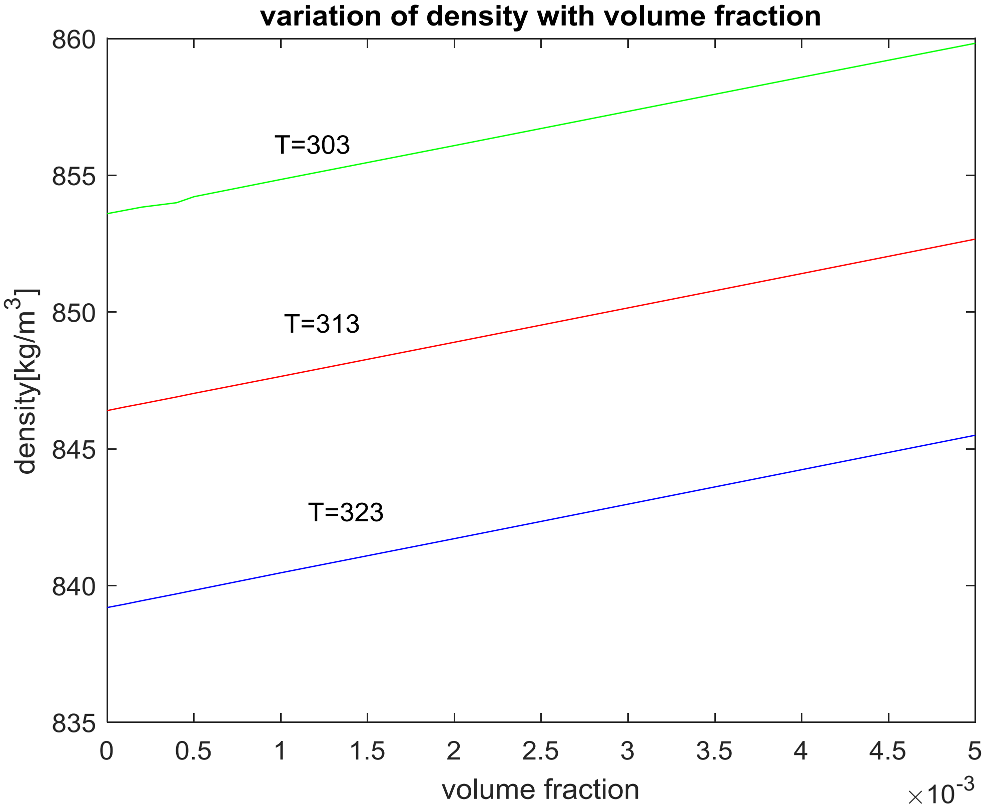

Fig. 1 Variation of density with volume fraction at T=303K, T=313K, T=323K

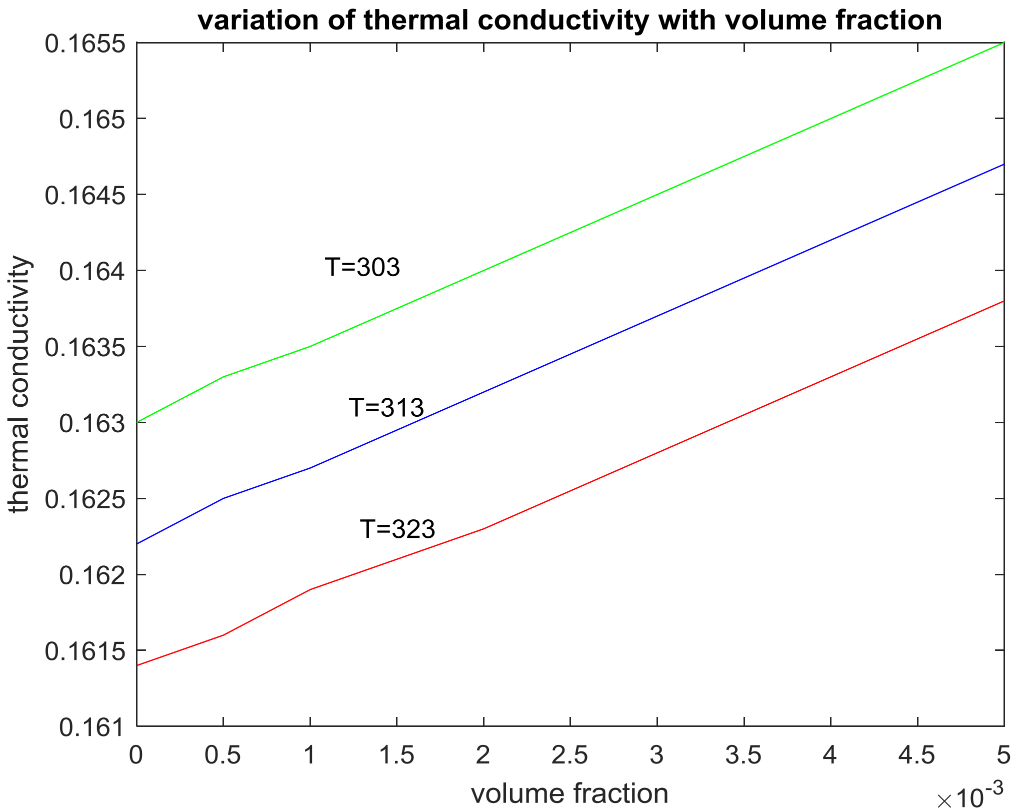

Fig.2 Variation of thermal conductivity(k) with volume fraction at T= 303K, T=313K and T=323K

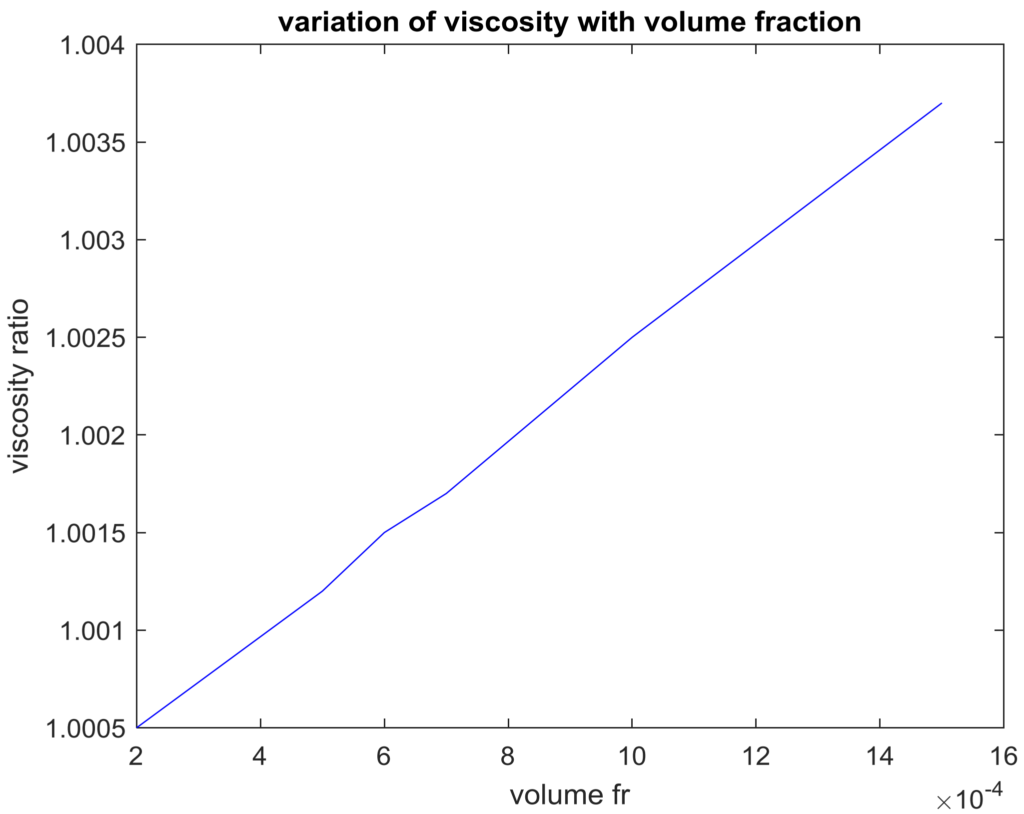

Fig.3 Variation of dynamic viscosity ratio with volume fraction

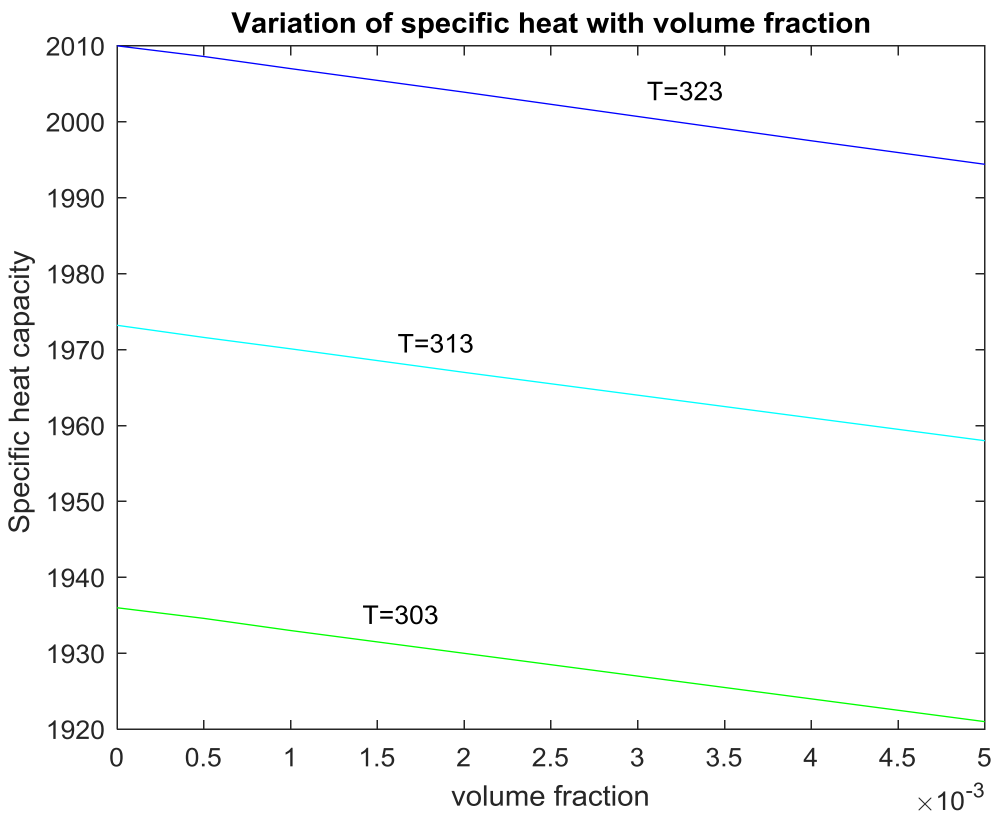

Fig.4 Variation of specific heat capacity with volume fraction ;temperatures T are in Kelvin.

For mwcnt-thermal oil nanofluid, the volume fraction plays an important role for the determination of the thermophysical properties. The graphs represent the variations of density(Fig.1), thermal conductivity,(Fig.2) viscosity(Fig.3) and specific heat capacity of the nanofluid(Fig.4) with volume fraction of mwcnt. Though the conventional model describes the thermophysical properties as a function only of the concentration of the nanoparticles, but substituting the properties of pure oil from correlations arrived at from experimental results, it has been possible to evaluate the thermophysical properties of the nanofluid at temperatures 303K, 313K and 323K.The viscosity of the nanofluid and its thermal conductivity play a very significant role in investigating heat transfer applications.

V. CONCLUSIONS

The variation of thermophysical properties with volume fractions of the mwcnt in thermal oil has been evaluated. The conventional [Hamilton Cross] model expresses the thermophysical properties with no dependence on temperature. However due to the industrial applications of nanofluid as a heat exchange medium ,the thermophysical properties of the base fluid which is thermal oil in the present study ,have been represented as a function of temperature. The correlations for the dependence of thermal oil properties on temperature have been adopted from the empirical correlations derived by Fontes[5], Pakdaman [16], Ilyas[32,33], Refie [28], Bethisti[2]. While there was an appreciable change in the density of nanofluid with temperature, the variation of density with volume fraction was small. This variation in density with temperature results in buoyancy force which drives heat transfer through natural convection. The reason for small alteration in density due to increase in the volume fraction can be attributed to the extremely small concentration of mwcnt. However, even at such low concentration of mwcnt , there is an appreciable increase in the thermal conductivity of the nanofluid with the change in volume fraction. This is particularly significant for increase in the efficiency of the heat transfer rate. The specific heat is not altered much with temperature but the addition of mwcnt particles reduces the specific heat capacity of the nanofluid. For industrial applications, therefore the conclusion is that the specific heat change with volume fraction is slightly more pronounced at lower temperatures. Finally increase in viscosity with the addition of mwcnt particles indicates an increase in higher pumping costs. Addition of mwcnt to thermal oil will therefore have an adverse effect on the heat transfer. However, for concentrations of mwcnt as low as 0.05%-0.5%, the viscosity alteration is small and therefore there is no appreciable cost increase. The conclusion from the present work is that addition of mwcnt to the thermal fluid can be designed as a nanofluid for an efficient heat removal. This is essential for an optimum performance of electronic devices, CPU cooling, in manufacturing industries, petroleum industry as also in the automobile industry where mwcnt can be an additive to the engine oil. Similar properties can be altered in transformer oil by the addition of mwcnt which has application in electricity distribution grid system. The drawback of this nanofluid as heat transfer medium is the stability issue. More experimental research is needed for synthesizing more stable mwcnt nanofluid. Natural convection is a cost- effective method of heat transfer which can be the heat transfer mode using mwcnt-thermal oil nanofluid. While addition of nanoparticle increases the thermal conductivity of the base fluid but thermal oil has the characteristic that with increase in temperature, its thermal conductivity decreases which can prove to be detrimental for heat transfer applications and hence more experimental data is needed to confirm that addition of mwcnt enhances the gross heat transfer at higher temperatures which is essential for industrial applications.

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