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A Review of MWCNT Nanofluid for Heat Transfer: Comparisons and Applications with different Base Fluids

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***Abstract*— Multiwalled carbon nanotubes when added to conventional cooling agents, enhances the heat transfer properties. This dispersion, called the carbon nanofluid has the potential of being used as a heat exchange medium in micro-electronic devices, manufacturing sector, automobile industries, aviation, petroleum industries, chemical production and in refrigeration applications. For designing efficient heat removing agent, it is important to make a detailed study of the thermophysical properties. The present work is a review of the recent studies on the stability, thermophysical properties and applications of this nanofluid. MWCNT having a high thermal conductivity is discussed as a material which when added to basic heat transfer fluids improves its heat transfer characteristics. It is found that the thermal conductivity, density and viscosity increase with the concentration of the nanofluid. However, the specific heat capacity decreases with the concentration of the nanoparticles. This work is further extended to investigate the thermophysical properties for different base fluids which have mwcnt dispersed in these fluids. Investigations of the thermophysical properties of CNF with water, Ethylene Glycol and Engine oil as base fluids, reveal that engine oil with mwcnt is superior to the other carbon nanofluids studied, for heat removing applications.**

***Index Terms* Heat transfer, Multiwall carbon nano tube, Nanofluid, Thermophysical Property,**

I. INTRODUCTION

With the miniaturization of electronic industry and the development of sophisticated communication devices, transportation, power generation sector, manufacturing industries and chemical production, the thermal management has emerged as one of the most formidable challenges. For optimization of performances of devices like transformers in electricity distribution system, it is imperative to remove the heat generated efficiently. Generally, the heat dissipated from a region can be expedited by increasing the surface areas or addition of fins. The structural augmentation can result in increase in dimensions and therefore weight of the equipment. An alternative method was suggested by Choi et al [1]. Addition of nanoparticles to basic coolants and preparing a stable dispersion for efficient heat removal was explored by these Scientists[2]-[5]. These fluids were named as nanofluids. Addition of solid particles to liquids for enhancing the heat removing capabilities is an ancient practice. However, due to miniaturization of channels through which the coolants flow, the micro solid particles result in clogging the pipes and causes the wear and tear of the walls. Replacing them by nano particles overcomes the problems of clogging. As these are lighter, the damage caused to the walls are drastically reduced. A lot of experimental work has been carried out on aqueous metals and metal oxides nanofluids [6]. This work is a review of recent experimental and numerical research on thermo-physical properties and heat transfer of multiwalled carbon nanotube added to base fluids. Amrohalli et al studied the effects of volume fraction and temperature on the thermophysical properties of carbon nanotube nanofluid(CNF)[7]. Duangthongsuk W studied the heat transfer through convection using nanofluids and calculated the convective heat transfer coefficient [8]. Bethisti et al studied the effect of adding mwcnt to transformer oil for heat transfer [9]. Ashthiani et al investigated experimentally the heat transfer characteristics of carbon nanotubes in oil placed in a tube with constant heat flux. Their conclusion was that heat transfer characteristics increased with the increase in concentration of mwcnt [10]. Hessam et al performed a critical study of the mwcnt nanofluid thermophysical properties[11]. Thermal conductivity enhancements of carbon nanotube nanofluid was explored by Huaqing et al [12]. Pakdaman studied experimentally the effect of mwcnt addition in oil for heat transfer in helical coils placed vertically [13].

Khalil et al analyzed the thermophysical properties of nanofluids in general [14]. Meyer et al studied the mwcnt water nanofluid as a single phase flow and explored the pressure drop for fluid flow in a tube with its walls at a constant heat flux[15]. The volume fraction considered was less than 1%. The mwcnt considered had internal and external diameters as 5 nm and 30 nm respectively and the length was 30 micrometre. Their conclusion was that the option of using mwcnt water nanofluid as a heat exchange medium was not viable since the increase in viscosity was much higher than the increase in thermal conductivity due to the addition of mwcnt to water. Higher viscosity implies higher pressure drops leading to higher pumping costs for the aqueous mwcnt. They also explored the effect of addition of surfactant to the nanofluid for increasing the stability of the nanofluid. Their conclusion was that thermophysical properties are altered by the addition of surfactant.

Since viscosity is an important thermophysical property in the evaluation of heat transfer , viscosity was experimentally evaluated for a range of volume fractions 0.05%-0.001%[16]. For a uniform dispersion of the cnt in the base fluid water, they added a surfactant and studied its influence. Addition of these surfactant often alters the thermophysical properties of the nanofluid. An alternative method to prepare a uniform dispersion is sonication which was used by Garg et al to prepare and study the heat transfer increase in mwcnt -water nano fluid. Their conclusion was an increase in viscosity with sonication time till a maximum value. After that a decreasing trend was observed [17]. Phuoc et al. [18] concluded from their experiments that the viscosity can be altered simply by changing the concentration of CNT in the base fluid. The dependence of nanofluid’s viscosity on size, shape and operating temperature of the nanoparticle, was investigated by Mahbubul et al. [19] and . Halelfadl et al. [20]. They explored the effect of temperature and concentration on the nanofluid viscosity using very low volume fractions. Their conclusion was that the aqueous CNT nanofluid behaved like a Newtonian fluid. However, at higher concentrations, the nanofluid behaved like a non-Newtonian fluid. The surfactant used was SDBS and the volume fraction was in the range of 0.0055%-0.278%. While, in the Newtonian range,the viscosity was found to be decreasing with temperature, in the non-Newtonian region, the viscosity of the aqueous cnt nanofluid was experimentally found to be temperature independent. Halelfadl et al. prepared the nanofluid by the two step method and concluded that the viscosity of the nanofluid is lower when the surfactant is added. They ascribed this to the formation of a more uniform dispersion with the surfactant. In the absence of the surfactant, there is a tendency of agglomeration of nanoparticles which resists the flow of nanofluids [21]. Wang et al also studied the convective heat transfer and concluded that the heat transfer was enhanced with the addition of CNT to water [22]. Kamali and Binesh [23] numerically studied the convective heat transfer of mwcnt nanofluids flowing through a tube with the wall at a fixed heat flux. Nazari et al used water, EG as base fluids and investigated the effect of CNT nanofluids for CPU cooling [24]. The cumulative effect of generation of heat from different components in the CPU is detrimental for the functioning of the computers. Hence an effective thermal management for the efficient running of the computer is essential. The above detailed study showed that there was a 22% and 20% decrease in the final CPU temperatures respectively, for CNT and Alumina water nanofluids as coolants. The basic problem in using nanofluids as a heat exchange medium is that their specific heat decreases with the volume fraction for almost all the nanoparticles including CNT. Silicon di oxide dispersed in molten salts $KNO_3 and\ NaNO_3$ show an increase in specific heat with volume fraction [25]. However, the temperature range for these salts are $>200℃$. For lower operation temperatures, the nanofluid cannot be prepared as these salts have high melting points and are required to remain in the molten state for a uniform nanofluid. In general, the density of all nanofluids increases with volume fraction and decreases with temperature. The current work is a comparison of thermophysical properties of multi walled carbon nanotubes in 3 different base fluids namely water, EG and engine oil. All thermophysical properties of mwcnt nanofluids with water ,EG and engine oil as base fluids are discussed simultaneously. Most of the earlier works discussed in this paper have focused on single base fluids and studied the thermophysical properties pertaining to that nanofluid [26]-[32]. Here, the basic idea is to analyze the suitability of base fluids for diverse industrial applications.

II. MATHEMATICAL DESCRIPTION

Thermophysical properties considered have been calculated using the effective medium theory [33]-[34]. It is presumed that the low concentration of cnt in base fluids can be considered as a single phase fluid with these thermophysical properties altered according to the effective medium theory. When these nanofluids will be used for real applications for heat transfer enhancement, assumption of single phase fluid becomes a simplified model and the features can be investigated with less computational costs. The carbon nanotubes being cylindrical in shape, the formula used in the effective medium theory for the calculation of thermal conductivity is way off from the experimental results. Hence in this work, Xue ‘s formula has been used for the calculation of thermal conductivity of CNF for all the 3 base fluids as a function of the volume fraction of cnt [35]. Their emphasis was on the fact that since these tubes are not spherical, their orientation and distribution in the fluid play a role in heat transfer for practical applications.

Nomenclature

ρ_s density of solid $[kg/m^3]$

ρ_f density of base fluid $[kg/m^3]$

ρ_{nf} density of nano-fluid $[kg/m^3]$

f volume fraction

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 $[Pa\ s]$

Effective Medium theory equations

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

$$c_{nf} = ((1-f) * \rho_f * c_f + f * \rho_s * c_s) / \rho_{nf} \quad (2)$$

$$\mu_{nf} = \mu_f * (1 + 2.5 * f) \quad (3)$$

Table 1. Properties of MWCNT

Density(kg/m^3)	Thermal Conductivity(W/mK)	Specific heat$\left(\frac{J}{kg\ K}\right)$
1600	3000	796

Table 2. Properties of Base fluids

Base Fluid	Density (kg/m^3)	Thermal Conductivity(W/mK)	Specific heat $\left(\frac{J}{kg\ K}\right)$	Viscosity $(Pa\ s)$
oil	884	0.144	1910	0.0135(320 K)
water	998	0.613	4179	0.001
EG	1110	0.26	2400	0.016

III. RESULTS

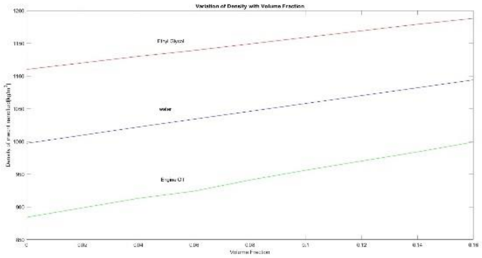

Fig. 1 Variation of Density of CNF with volume fraction of mwcnt

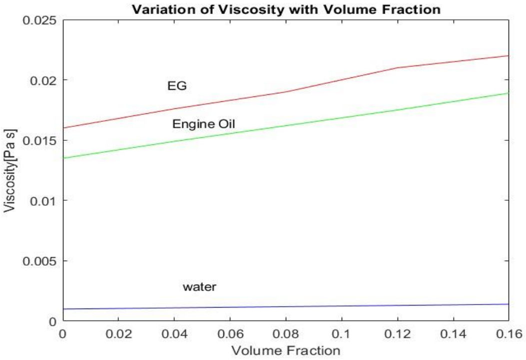

Fig. 2 Variation of Viscosity of CNF with volume fraction of mwcnt

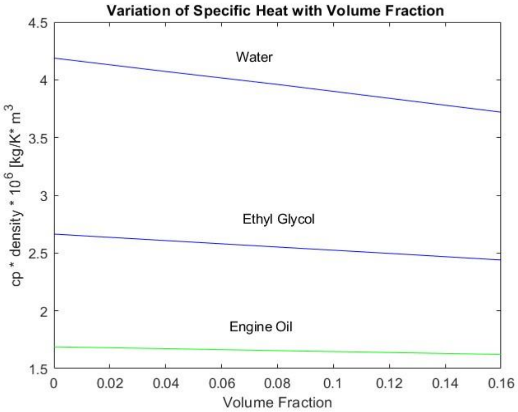

Fig. 3 Variation of Specific Heat with volume fraction of mwcnt

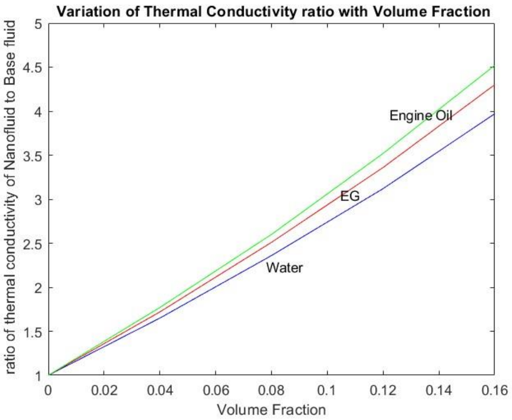

Fig. 4 Variation of ratio of Thermal Conductivity Ratio with volume fraction of mwcnt

Thermophysical Properties have been expressed graphically for the three base fluids. Fig. 1 represents the variation of density of mwcnt nanofluid (CNF) for the base fluids Water, Ethylene Glycol and Engine Oil. With volume fraction, the density of CNF increases linearly. The effective medium theory has been used for evaluating the density of CNF. It is important to note that for applications of nanofluids for heat transfer, in natural convection, it is the variation of density with temperature that causes the onset of convection. In fact a basic assumption, called Boussinesq approximation is often invoked,in systems where heat transfer involves convection. All other thermophysical properties are assumed to be constant with temperature. Fig.2 compares the viscosity of CNF for all the three base fluids. Viscosity plays an important role in heat transfer as well as rheological applications. As expected, the viscosity increases with the volume fraction. However, theoretically, the increase in viscosity for small volume fractions, is minimal. This result is highly significant. Higher viscosity implies higher pressure drop resulting in the requirement of higher pumping power and hence an increase in the cost. Fig. 3 is a depiction of the specific heat variation with volume fraction. A decreasing trend with volume fraction is observed. The steepest fall in specific heat with volume fraction is observed for aqueous mwcnt. For Engine oil CNF, the variation of specific heat with volume fraction is the least. Fig.4 is a representation of the ratio of the thermal conductivity of CNF to the thermal conductivity of the base fluid. The base fluids are water, EG and engine oil. For small volume fractions, the ratio is a constant. However, for higher volume fractions, the ratio is highest for CNF with engine oil.

IV. CONCLUSIONS AND FUTURE RESEARCH

Theoretical calculations are very useful for investigating the thermophysical properties of CNF. It avoids the usage of excess chemicals that may be needed to study the effect of various parameters. Theoretical work, computations and simulations save a lot of time as also avoids negative effects of using chemicals for several trial purposes. A sound background can be prepared by testing the system computationally over a range of parameters. Each of the CNFs with different base fluids have applications in different industrial sectors. A very common application of cnt water nanofluid in solar applications is the desalination process where the evaporation of saline water using solar radiation absorption can produce potable water. If a heat exchanger with CNF is used, the evaporation rate can be enhanced and the yield of drinking water from saline water can be accelerated [36]. Water CNF as well as hybrid CNF with a combination of water and EG as base fluids can be used in heat exchangers. Due to better heat transfer characteristics, smaller amount of nanofluids will be required. This can result in lighter and more compact heat exchangers. In particular, for the aviation industry, the CNF can replace the conventional heat exchange medium. This study is significant in suggesting that the engine oil as a base fluid for CNF will be the most efficient heat transfer fluid amongst the three CNFs studied. As stated earlier, engine oil and thermal oil are effective heat removing medium[37]-[40]. It has applications in transformers in electricity distribution system. Augmenting the base fluid by mwcnt can improve the life span as well as the performance of these devices. A big challenge is the synthesis of CNF. For industrial applications, stability is of immense importance. The costs involved in preparation of mwcnt need to reduce. Future research should entail innovations for reducing the cost of production of these nanofluids. Second challenge is to reduce the mismatch between the theoretical values and the actual experimental results. Artificial Intelligence (AI) needs to be employed for a more accurate prediction of theoretical thermophysical properties. Perhaps the models considered in the present study is too simplified. There could be a lot more variables on which the thermophysical properties depend. AI can factor in a lot more variables and project a better convergence with the experimental conclusions.

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