International Journal of Engineering
Journal Homepage: www.ije.ir

RESEARCH NOTE

An Experimental Study on Thermophysical Properties of Multiwalled Carbon Nanotubes

M. Thakur*[a], D. Gangacharyulu[b], G. Singh[a]

[a] *Department of Mechanical Engineering, Chandigarh University, Gharuan, Punjab, India*
[b] *Chemical Engineering Department, Thapar University, Patiala, Punjab, India*

PAPER INFO

Paper history:
Received 29 March 2017
Received in revised form 26 June 2017
Accepted 07 July 2017

Keywords:
Multiwalled Carbon Nanotubes
Thermophysical Properties
Nanofluids

ABSTRACT

Nanofluids are the heat transfer fluids having remarkable thermal properties. The paper presents the experimental analysis of thermal conductivity, density, specific heat and viscosity of multiwalled carbon nanoparticles dispersed in water at various temperatures and particle concentrations. To examine the forced convection heat transfer of Multiwalled Carbon Nanotubes (MWCNT)-water nanofluid, the assessment of thermophysical properties are necessary. The two-step method was used to prepare the nanofluids with gum arabic surfactant. The thermophysical properties were measured using different volume concentrations (i.e. 0 – 0.9 vol.%) of nanoparticles and various temperatures (i.e. 30°C to 70°C). The thermal conductivity, specific heat, density and viscosity were measured with the help of KD2 Pro Thermal Property Analyser, Differential Scanning Calorimeter, KEM-DA 130N - Portable density meter, Brookfield LVDV-III ultra-programmable viscometer. The experiment found an enhancement in thermal conductivity and specific heat with rise in temperature whereas viscosity and density decreases with increase in temperature. On the other hand the thermal conductivity, viscosity and density increases with increase in MWCNT's concentration but the specific heat was found to diminish with a rise in particle concentration.

doi: *10.5829/ije.2017.30.08b.15*

NOMENCLATURE

C_p	Specific heat		
		Subscripts	
Greek Symbols		f	Base fluid
ρ	Density	nf	Nanofluid
φ	Volume fraction	p	Particle

1. INTRODUCTION

Nowadays, with growing demands and market competition, the development of the energy efficient machines or equipment in various industrial operations like the air conditioning, transportation, microelectronics, refrigeration and the like have taken a trend. The thermal system is the most important concern in any energy-efficient machine which includes the heat transfer fluid. Earlier, water, ethylene glycol and similar materials . were mainly used as the heat transfer fluid in the industry processes and equipment, but these fluids possess low thermal conductivity. To overcome this concern, number of researches were conducted to boost the thermal properties of the conventional heat transfer fluid with numerous improvement methods. The most suitable solution to this came by dispersing the highly conductive nanoparticles with the base fluid which further was coined as nanofluids by Choi [1]. When the nano-sized particles are suspended in the liquid it forms a nanofluid which possesses large thermal conductivity and long-time stability at low particle concentration as compared to the micro-sized and millimetre-sized particles. The

*Corresponding Author's Email: *mohitpeace1@gmail.com* (M. Thakur)

enhancement in the heat transfer and thermal conductivity by suspending nanoparticles in conventional fluids over the basic base fluids have been reviewed by W. Yu [2]. Nanofluids due to their exceptional features finds wide range of applications in the area of heat transfer technology.

Over decades, we have been using various types of nanoparticles like Al, Cu, Al_2O_3, CuO, SiO_2, carbon nanotubes, etc. Among the different nanoparticles, carbon nanotubes (CNT) is a good choice due to its remarkable and unique properties like it possesses high thermal conductivity of 2000-3000 W/m-K and high aspect ratio [3]. S. Iijima [4] observed the fibrous nature of the carbon nanotubes (CNT). Ding et al. [5] reported the dispersion of CNT in the nanofluid uniformly using a straight copper tube which further acquires large convective heat transfer improvement under a streamline flow in relation to water for low Reynolds number and weight fraction in nanotubes. They also found an enhancement in viscosity and thermal conductivity with temperature rise and nanoparticle concentration. There has been many investigations in previous few years regarding the thermal conductivity enhancement when CNTs were added in poly oil, water, ethylene glycol, which saw an enhancement of 15% to 160% in thermal conductivity at small volume concentration [6-9].

The flow properties of CNT with water as the base fluid inside a horizontal tube has been measured by Ko et al. [10] and reported the effect of concentration on nanofluids shear thinning behaviour which further lead to pressure drop increase under laminar flow in contrast to the base fluid. Ruan and Jacobi [11] studied the various heat transfer properties of multiwalled carbon nanotube (MWCNT) nanofluid with a low volume concentration of 0.24 in intertube falling film flow. They found higher enhancement with ethylene glycol than water in a streamline flow at same Reynolds number. Garg et al. [12] reported an increase in thermal conductivity by 20% at 1wt% MWCNT-water nanofluid for 113 J/g optimum ultrasonic energy. Ganesh et al. [13] discussed the effect on thermophysical properties of MWCNT nanoparticles dispersed in water-ethylene glycol mixture. The results showed that the thermal conductivity increase with rise in concentration and an enhancement of 11% was noted at 0.9% concentration and there is a decrease in specific heat with increase in concentration while viscosity ratio increases with rise in temperature. Gohari et al. [14] experimentally discussed the impact of volume fraction on the thermal conductivity of both single walled carbon nanotubes (SWCNT) and multi-walled carbon nanotubes (MWCNT). They found the thermal conductivity of nanofluids containing single-walled carbon nanotubes higher than the multiwalled carbon nanotubes, along with it they also studied an increase in thermal conductivity with a rise in temperature and volume concentration. M.Tajik and Zamzamian [15] experimentally measured the thermal conductivities of Cu and Al-water nanofluids with the help of thermal property analyser. The results showed that the thermal conductivity of Cu/water nanofluid is higher than that of Al/water nanofluid. They also found that the nanofluids are having higher thermal conductivity in comparison to base fluid.

Chiam et al. [16] experimentally studied viscosity and thermal conductivity of Al_2O_3 nanofluid at different ratios of base fluid and reported an increase in thermal conductivity with increase in volume concentration, temperature and the ethylene glycol percentage and also found an enhancement in thermal conductivity of 2.6 to 12.8% with base ratio, whereas the viscosity increase at increase in volume concentration but on the other hand there is a sudden decline with a rise in temperature and concentration. Farbod and Ameneh [17] stated that the thermal conductivity of decorated MWCNT based nanofluid is way much higher than the undecorated one, that is 0.16%-8.02%. Chen Li et al. [18] experimentally investigated thermophysical properties of visco-elastic fluid based nanofluids (VFBN) containing MWCNT's at different temperature, volume fraction and base fluids concentration. The thermal conductivity of the base fluid is less as compared to VFBN, it increases with increase in temperature and volume fraction. They also found that with decrease in temperature and increase in volume fraction the shear viscosity increases due to which VFBN with MWCNT behaves as a non-Newtonian fluid. In recent studies, models on the basis of group method of data handling (GMDH) had been developed to measure the viscosity of nanofluids and thermal conductivity of pure ionic liquids and ionanofluids. The results shows that the average relative deviation for viscosity is 2.14% and for thermal conductivity is 1.79%. They also found that the viscosity predicted by the hybrid model is highly accurate and for thermal conductivity prediction the mGm model is a better choice in comparison to Maxwell model [19, 20].

Halelfadl et al. [21] experimentally found the effect of temperature and nanoparticle concentration on viscosity of MWCNT/ water nanofluid. Their results showed that the relative viscosity of the nanofluids having high shear rate have no effect on temperature and they also found the importance of rheological characterisation and structural information of nanofluid mixture. Jamshidi et al. [22] experimentally studied the impact of SiO_2 nanoparticles on the viscosity of the base fluid where they used water, ethylene glycol-water and transformer oil as base fluids. The results showed an enhancement in viscosity of the solution with increase in nanoparticles and as a rise in temperature the viscosity of the base fluid and nanofluid decreases. They also discussed the effect of heating and cooling on nanofluids viscosity. Atashrouz et al. [23]

experimentally investigated the rheological behaviour of ethylene glycol/water/Fe_2O_3 nanofluids and also examined the effect of shear rate on the viscosity of the nanofluids. They found that the viscosity decreases with increase in shear rate. Furthermore, they used a hybrid group method of data handling polynomial neural network for predicting the viscosity. There also has been some experimental studies which discusses various thermophyscial properties of nanofluid at various concentrations and temperatures. They found that with an increase in particle concentration and temperature, there is an enhancement in thermal conductivity which is due to the increase in particle movement as a result of rise in temperature [24-26].

From the above literature, there are many things that have to be kept in mind regarding the use of carbon nanotubes as the heat transfer fluid. The aim of the study is to measure the different thermophysical properties of water based MWCNT nanofluids at different temperatures and particle concentration which can be used for the different heat transfer equipment.

2. NANOFLUID PREPARATION

The MWCNT were bought from Nano Labs, Jamshedpur, India. The geometrical specifications and characteristics of CNT are listed in Table 1. The XRD and SEM images of MWCNT are shown in Figures 1 and 2, respectively which shows the presence of entanglements between the CNT particles. At the present study, the nanofluid with various nanoparticles concentrations (0.1, 0.3, 0.5, 0.7, and 0.9 v/v) were prepared. The deionized water (DIW) was used as a base fluid, gum arabic as the surfactant and multiwalled carbon nanotubes (MWCNT) as nanoparticles. The surfactants were used to remove the agglomerations and modification of nanoparticles in the nanofluids along with this; it also increases the stability of nanoparticles in aqueous mixtures. The most important part is to add the proper amount of surfactant which should coat the CNTs surface.

TABLE 1. Characteristics and geometrical specifications of multiwalled CNT's

MATERIAL	MWCNT
Appearance	Black
Purity	>98%
Diamater	18-20 nm
Length	Av. 20 μm
SSA	330 m^2/g
Density	0.20-0.35 g/cm^3

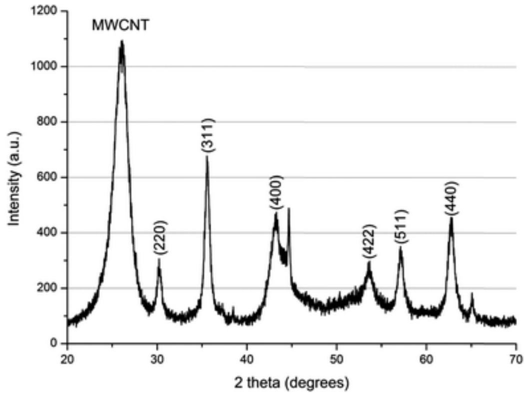

Figure 1. XRD photograph of MWCNT nanoparticles

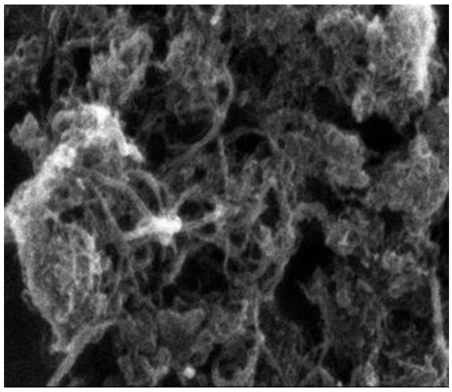
Figure 2. SEM photograph of MWCNT nanoparticles

A 0.25 wt% surfactant was added to base fluid and was then magnetically mixed for 60 minutes; further, the multiwalled carbon nanotubes nanoparticles were added to the solution. The solution was then transferred to the ultrasonicator for sonication to achieve a uniform dispersion of the particles in the base fluid. The sonication was done by ultrasonicator which was placed in a water bath at 20 kHz frequency for almost 3 hours. The stability of the nanofluids were determined by UV spectroscopy.

3. EXPERIMENTAL PROCEDURE

3. 1. Thermal Conductivity The measurement of thermal conductivity with respect to temperature is the most important factor for the evaluation of convective heat transfer coefficient of numerous operations. Several techniques have been used for measuring the thermal conductivity of nanofluids including cylindrical cell, hot wire or transient hot wire (THW) and steady state parallel plate method. In this study, we used KD2 Pro Thermal property Analyser (Decagon Devices Inc., USA). It measures thermal conductivity using the transient line heat source method. The device consists of a sensor needle know as KS-1 sensor which is 1.2 mm in diameter and 60 mm long, the sensor is further used to measure nanofluids thermal conductivity ranging 0.002–2.00 W/mK and accuracy ± 5% in a temperature range of 30°C-70°C. A heating/refrigerating temperature controller bath with an accuracy of ± 0.01 °C was used to maintain the desired temperature of the nanofluids. A 25ml nanofluid was poured into a cylindrical glass container. A flexible nylon lid was fitted on the container through which the sensor needle was embedded right at the centre for measuring more precise values and one minute scan time was configured for measurement. All the measurements were taken 3 times and average value was taken into consideration and the values were only obtained once the nanofluids attained the desired temperature.

3. 2. Specific heat The device DSC 4000 model (Differential Scanning Calorimeter, Perkin Elmer, USA) was used to measure specific heat of MWCNT based nanofluid. Specific heat at various concentrations 0 – 0.9 vol.% and temperatures 30 - 70°C at an interval of 10°C were measured. A 22mg of nanofluid sample was planted on the aluminium pan having a scanning rate of 3°C min^{-1} .The reading are measured thrice and finally an average value is considered. The following Equation (1) has used for comparison with the experimental readings.

$$\left(C_p\right)_{nf} = \frac{(1-\varphi)\rho_f C_{p.f} + \varphi\rho_p C_{p.p}}{\rho_{nf}} \tag{1}$$

3. 3. Density A KEM-DA 130N (a portable density meter) was used to measure the density of MWCNT based the nanofluid which ranges from 0–2000 kg/m^3. A nanofluid from 0–0.9% volume concentration under temperature 30–70°C was measured with a precision of ±0.001 kg/m^3. All the values are taken thrice for more precision and then further on the average value is used for calculations. The experimental value of the density is then compared with the model which uses Equation (2).

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_p \tag{2}$$

3. 4. Viscosity The viscosity of the MWCNT-water nanofluid at different concentrations and temperatures were measured with the help of Brookfield LVDV-III ultra-programmable viscometer which was further connected to a personal computer which was used for storage and data collection. The spindle was attached to the viscometer which was further inserted into the sample jacket containing the nanofluid. Due to the deflection of the calibrated spring, a viscous drag was created against the spindle. The instrument measures the values from 1MPa.s to 6,000,000 MPa.s with an accuracy of ±1.0% and 0.1°C temperature accuracy and temperature ranging from -20°C to 100°C. Spindle model ULA-49EAY has been used here and the temperature of the bath can be circulated by an adapter. The viscosity was measured from 0 to 0.9 vol.% with temperature from 30-70°C at an interval of 10°C. Three readings has been taken at each point and the average of the values is presented for analysis.

4. RESULTS AND DISCUSSION

4. 1. Thermal Conductivity Figure 3 shows the thermal conductivity of nanofluid (MWCNT-water) at various concentrations (0%, 0.1%, 0.3%, 0.5%, 0.7% and 0.9%) and temperatures (30, 40, 50, 60 and 70°C). The thermal conductivity of the base fluid and the nanofluid increases with increase in temperature and the volume concentration. The data shows that the nanofluid possesses higher thermal conductivity in contrast to the base fluid at each volume concentration. This is due to the random Brownian motion of the nano-sized particles with rise in temperature. This temperature dependence of thermal conductivity was discussed by Xiao et al. [27]. The Brownian motion of the nanoparticles leads to increase in thermal conductivity of the nanofluid with rise in temperature. The major logic behind an enhancement in thermal conductivity of CNT based nanofluid is due to the CNT nanoparticles. The base fluid at 30°C possesses thermal conductivity of 0.619 W/m-K and at similar temperature 0.9 vol.% naofluid was having thermal conductivity 0.705 W/m-K which is 13% higher than the base fluid. This clearly shows that with increase in volume concentration the thermal conductivity of the nanofluids increases. Similar trends with higher enhancement were discussed by Choi et al. [7] and Xie et al. [8]. At 70°C, the thermal conductivity of 0.9 vol.% and the base fluid were 0.828 W/m-K and 0.660 W/m-K, respectively with an enhancement of 25%. Xing et al. [28] also discussed the similar results of carbon nanotubes for low concentration having thermal conductivity of 8.1% for S-SWCNT, 16.2% for L-SWCNT, 5.0% for MWCNT. For every single case, it is shown that nanofluid is having higher thermal conductivity in comparison with the base fluid. From the data, an increasing trend in thermal conductivity of nanofluid at various volume concentration and temperatures has been observed. The higher surface area of CNT nanoparticles is the main reason for enhancing thermal conductivity as it provides larger contact area with its base fluid, which further lead to reduction of contact resistance in CNT's fluid interface.

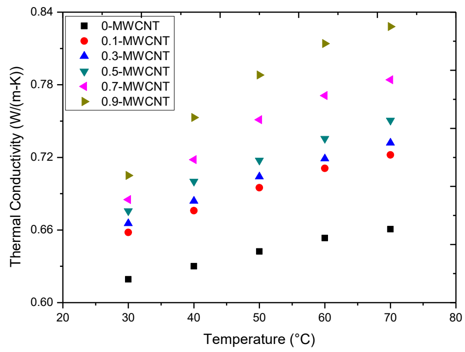

Figure 3. Thermal conductivity of MWCNT's nanofluid at different temperatures and concentrations.

4. 2. Specific Heat: The specific heat measurement of base fluid and nanofluid at various concentrations (0%, 0.1%, 0.3%, 0.5%, 0.7% and 0.9%) and temperatures (30°C, 40°C, 50°C, 60°C, 70°C) with DSC is shown in Figure 4. The specific heat tends to increase with rise in temperature and the trend was consistent and straight line. However, with the rise in volume concentration, the specific heat decreases. This is due to low specific heat of the added particles contrasted with the base fluid. The higher specific heat of the mixture in comparison to the nanoparticle is due to large specific heat of the base fluid. From Figure 4. the specific heat of base fluid at 30°C and 70°C were 4178 J/kg.K and 4191 J/kg.K, whereas at 30°C and 70°C, 0.9% vol. concentration is 4147 J/kg.K and 4159.94 J/kg.K. From the values it means, the quantity of heat required to rise the temperature of the nanofluid is nearly lower in comparison to the base fluid. It can be seen that gaps between the two concentrations were same but the gap between two declining lines were not same. The similar trend were also shown by Elias et al. [29], they computed the reduction of 5.08% in specific heat of Al_2O_3 nanoparticles at 1.0% vol.

concentration and 10°C to 50°C temperature and a deviation of 4.5% in experimental value from the theoretical value were measured by them. Ganesh et al. [13] also found a reduction of 28% at 5°C and 23% at 40°C in specific heat with 1.5 wt.%.

4. 3. Density The Figure 5. portrayed the densities of MWCNT - water nanofluid with different temperature (30°C, 40°C, 50°C, 60°C, 70°C) and different concentrations (0%, 0.1%, 0.3%, 0.5%, 0.7% and 0.9%). It is shown that the density of MWCNT based nanofluid increases with increases in volume concentration by increasing temperature, whereas there was a reduction in density along with temperature rise. The base fluid possess the lowest values of the densities in comparison to the increasing nanofluid concentration. The results predicted the density of the base fluids at various temperature that are 995.2 kg/m^3 at 30°C to 977.7 kg/m^3 at 70°C, similarly the density of the nanofluid in 0.9% concentration at 30°C and 70°C were 996.66 kg/m^3 and 979.3 kg/m^3. The measured value are further compared with the equation (2) by taking the density of MWCNT as 2100 kg/m^3 and base fluid as 1066 kg/m^3. The concept of molecular dynamic simulation was presented by Alessio Alexiadis and Stavros Kassinos [30]. They studied that the MWCNT are filled with the base fluids molecules in various forms like wire mode, bulk mode and layer mode which further lead to non-uniform density variation in high interfacial region with higher vander wall forces.

4. 4. Viscosity The viscosities of MWCNT based nanofluid and the base fluid were measured for various temperatures (30, 40, 50, 60 and 70°C) and volume concentrations of nanoparticles ranging from 0%, 0.1%, 0.3%, 0.5%, 0.7% &, 0.9% vol.% and is presented in Figure 6. It is shown that with increase in temperature, the viscosity tends to decrease. The base fluid is having lower viscosity in comparison with the nanofluid at various volume concentrations.

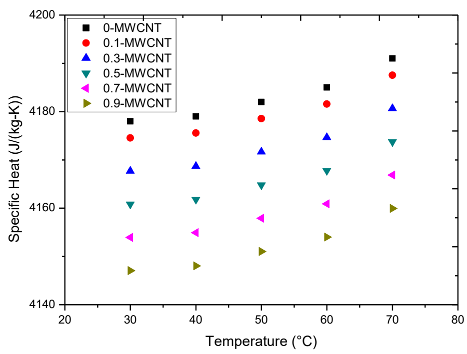

Figure 4. Specific heat of MWCNT's nanofluid at different temperatures and concentrations.

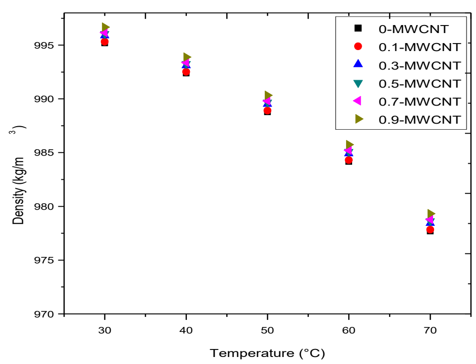

Figure 5. Density of MWCNT's nanofluid at different temperatures and concentrations.

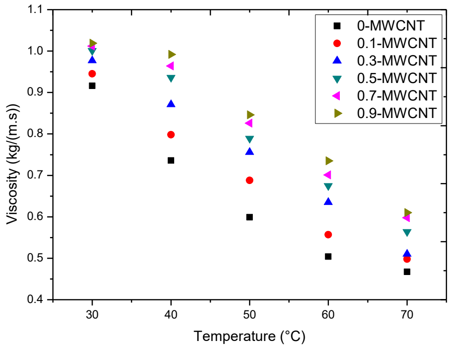

Figure 6. Viscosity of MWCNT's nanofluid at different temperatures and concentrations.

It is noted that as we increase the nanoparticles concentration in the base fluid the viscosity enhances and decreases with rise in temperature. The viscosity of the base fluid falls as much as 47.2% when the temperature increases from 30°C to 70°C. Whereas nanofluids viscosity decrease by 7.9% when the temperature is increased from 30°C to 70°C. This is due to the increase in the random action among the molecules of the material. This trend is commonly observed in most of the liquids, as the movement of the molecules are much higher than the viscosity decreases. The results show that for low concentration of nanoparticles of MWCNT in base fluid, the nanofluids demonstrate the Newtonian behaviours.

Similar trends were shown by the Kumaresan et al. [31]. They showed the rheological behaviour of MWCNT based nanofluids and found that the viscosity of the nanofluids particularly depends upon the aspect ratio and concentration of the carbon nanotube. Chen L. et al. [32] found that the MWNCNT/EG+Water nanofluids are having lower viscosity than the base fluid, if the volume fraction is low and this is due to the lubricative effect of the nanoparticles. Elias et al. [29] also discussed similar decreasing trend of the viscosity exponentially with increasing temperature. They found 150% highest viscosity enhancement of 1% volume Al_2O_3-RC nanofluid at 10°C and lowest 4% for 0.2 vol % nanofluid.

5. CONCLUSIONS

The thermophysical properties of the multiwalled carbon nanotubes (MWCNT) based nanofluids were measured experimentally at different temperatures and concentrations. It was noticed that with a rise in temperature from 30°C to 70°C, there was an increase in thermal conductivity and also greater enhancement in thermal conductivity was noticed at higher nanoparticle concentrations. An enhancement of 25% was found at 0.9% vol. MWCNT. The specific heat was found to be increasing with rise in temperature and further it declines with increase in nanoparticles concentration. The density decreases with rise in temperature, whereas with increasing particle concentration, density also increases. Similar trends were also given by viscosity as it increased with increase in temperature and decreased with increase in MWCNT's concentration in nanofluid.

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An Experimental Study on Thermophysical Properties of Multiwalled Carbon Nanotubes

RESEARCH NOTE

M. Thakur[a], D. Gangacharyulu[b], G. Singh[a]

[a] *Department of Mechanical Engineering, Chandigarh University, Gharuan, Punjab, India*
[b] *Chemical Engineering Department, Thapar University, Patiala, Punjab, India*

P A P E R   I N F O

Paper history:
Received 29 March 2017
Received in revised form 26 June 2017
Accepted 07 July 2017

Keywords:
Multiwalled Carbon Nanotubes
Thermophysical Properties
Nanofluids

چکیده

نانوسیالات، مایعات انتقال گرما با خواص حرارتی قابل توجهی هستند. مقاله تحلیلی آزمایشی هدایت حرارتی، تراکم، گرمای ویژه و گران‌روی نانوذرات کربنی چند دیواره در آب را در غلظت ذرات و دماهای مختلف ارائه می‌دهد. برای بررسی انتقال حرارت اجباری از نانولوله‌های کربنی پراکنده در آب ارزیابی خواص ترموفیزیکی ضروری است. روش دو مرحله‌ای برای تهیه نانوسیم‌های با سورفکتانت صمغ عربی استفاده شد. خواص ترموفیزیکی با استفاده از غلظت‌های مختلف (به عنوان مثال ۰–۰٫۹٪ حجمی) نانوذرات و دماهای مختلف (از جمله ۳۰ تا ۷۰ درجه‌ی سانتی‌گراد) اندازه گیری شد. هدایت حرارتی، گرمای ویژه، تراکم و گران‌روی با کمک تحلیل‌گر گرمایی KD2، Calorimeter Scanning و کالری‌متر تفاضلی ، چگالی‌سنج قابل حمل KEM-DA 130N، ویسکومتر Ultra-programmable LVDV-III Brookfield اندازه گیری شدند. این آزمایش‌ها افزایش هدایت حرارتی و گرمای ویژه با افزایش درجه حرارت ر ا نشان دادند، در حالی که گران‌روی و چگالی با افزایش دما کاهش می‌یابد. از سوی دیگر هدایت حرارتی، گران‌روی و چگالی با افزایش غلظت MWCNT افزایش می‌یابد، اما با توجه به افزایش غلظت ذرات، گرمای ویژه کاهش می‌یابد.

***doi**: 10.5829/ije.2017.30.08b.15*