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Experimental investigation of the thermal conductivity of hybrid nanofluids in the presence of Ag/ MWCNT nanocomposite particles

Scientific research paper

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ABSTRACT

The presence of nanoparticles enhances heat transfer in heat exchangers. The degree of enhancement depends on the type, size, and shape of nanoparticles, as well as temperature conditions. Therefore, this study aims to improve thermal conductivity in a hybrid nanofluid by incorporating a nanocomposite. Due to their high thermal conductivity, spherical-shaped silver nanoparticles are suitable for synthesizing composites with cylindrical-shaped functionalized multi-wall carbon nanotubes. The characteristics of the synthesized nanocomposite were investigated via UV-Vis spectrophotometer, SEM, and TEM analyses. Also, the effects of Ag concentrations and temperature on thermal conductivity were investigated. The thermal conductivity can be enhanced by 15%, increasing Ag concentration from 0.05-0.5 wt.% and temperature in the 20-45 C range. The stability of the synthesized MWCNT/Ag nanofluid was evaluated after more than 90 days. The results indicated that the nanofluids with lower concentrations of Ag nanoparticles preserved their stability without using a surfactant.

1 Introduction

Common heat transfer fluids usually have low thermal conductivity coefficients. However, adding nanoparticles can significantly increase the fluid's thermal conductivity due to their high thermal conductivity. These improved fluids, known as nanofluids, are created by dispersing nano-sized particles in regular fluids as they offer great potential for industrial applications [1,2]. The nanoparticles used in nanofluids are usually composed of metals such as copper, silver, etc., or metal oxides such as aluminum oxide, copper oxide, etc. [3]. Using Nanofluids with high thermal conductivity can help reduce fuel consumption, which is important from an environmental and economic perspective [4].

Previously, particles added to fluids were of micrometer dimensions, leading to poor suspension stability and quick settling [5]. This often causes blockage of fluid passages. On the other hand, nano-sized particles form much more stable suspensions and have low settling speeds, reducing the risk of clogging

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and blockage in channels [2]. Enhancing thermal performance is crucial for improving the efficiency of heat exchangers and heating/cooling systems in various industries, such as the petrochemical industries [2]. By adding and suspending nanoparticles, heat transfer can be increased without altering the size of the heat transfer surface. Consequently, there is no need to escalate fluid speed and level, resulting in cost savings. The concentration, size, and shape of nanoparticles affect the heat transfer coefficient in heat exchangers [6]. Moreover, in the long run, optimal heat transfer with a smaller volume of fluid reduces the harmful effects of the fluid on pumps and heat exchanger walls, thus reducing the negative impact on industrial equipment [7].

Various nanoparticles with high thermal conductivity were used for synthesized nanofluids. The water-based nanofluids have been synthesized with functionalized multi-walled carbon nanotubes (MWCNT) and metals such as Ag, Cu, Fe, and Zn. Cu, Fe, Ag, where Zn was reported to provide the highest stability and thermal conductivity [2]. Also, the effect of adding Ag nanoparticles to carbon nanotubes (pure and functionalized) on the thermal conductivity of nanofluids has been investigated. It was found that the thermal conductivity can be increased by 20.4% with functionalized MWCNTs and an Ag concentration of 4 wt% at 40°C [8]. Also, the hybrid nanofluid of MWCNT-COOH and Ag was synthesized with different concentrations of MWCNTs. The TEM, SEM, and XPS were carried out to investigate the characteristics of nanofluid. According to the results, it was shown that the ratio of thermal conductivity has increased non-linearly with increasing MWCNT concentration and temperature [7]. The hybrid nanofluid of MWCNTs and Ag was synthesized via an electric pulse evaporation. The maximum absorbance of 2.5 (A.U) was observed at 264 nm for nanofluid with MWCNT (0.05 wt.%)/ Ag(3 wt.%) [9]. The thermal conductivity of nanofluid can be enhanced by adjusting the volume mixing ratio of nanoparticles (Cu-Al/Ar) [10]. The experimental measurement and regression model was reported for the thermal conductivity of Al_2O_3 and GO-based mono and hybrid nanofluid. The hybrid nanofluid shows higher thermal conductivity than the mono nanofluid [11]. Also, molecular dynamics simulation was carried out to predict of the thermal conductivity of a nanofluid consisting of ethylene glycol (EG) based single-walled carbon nanotube (SWCNT). The simulation results were compared with experimental data [12]. A 2- 2-level factorial design was employed to investigate the effects of temperature and Ag weight fraction on the viscosity of nanofluids containing MWCNT and Ag. models for the prediction of viscosity were significant based on the variance analysis [13]. Thermal conductivities of two nanofluids with different weight fractions of MWCNT, CuO, and SiO_2 have been compared. Appropriate thermal conductivity enhancement was obtained with nanofluid containing higher percentages of MWCNT and CuO [14]. The effects of the shapes of single-wall carbon nanotubes on the heat transfer properties of nanofluids with water, engine oil, and ethylene glycol bases have been investigated numerically. The appropriate heat transfer properties can be obtained with lamina shape [15].

Due to the appropriate synergistic effect of functionalized MWCNTs and Ag nanoparticles on enhancing thermal conductivity, the synthesis of a water-based hybrid nanofluid using MWCNTs-COOH and varying concentrations of Ag has been investigated in the current study. The nanocomposite's morphology and distribution were analyzed using a UV-Vis spectrophotometer, SEM, and TEM. The impact of temperature and Ag concentration on thermal conductivity was also explored.

2 Experimental

2.1 Materials

A carbon nanotube, multi-walled, carboxylic acid functionalized (MWCNTs-COOH, 30-50 nm) has been prepared from the US Research Nanomaterials, Inc. Furthermore, silver nanoparticles have been purchased from the US Research Nanomaterials, Inc. The characteristics of silver nanoparticles are presented in Table 1.

Table 1. The characteristics of Ag nanoparticles

Density (g/cm^3)	Purity (%)	SSA (m^2/g)
10.5	99.99	18-22
Size (nm)	Color	Morphology
20	black	spherical

2.2 Synthesis of hybrid Nanofluid

The following procedure synthesized a water-based nanofluid (Fig. 1). Carboxylated multi-walled carbon nanotubes and Ag nanoparticles were added to deionized water in two separate beakers. Each mixture was then stirred vigorously at the temperature 20℃ using a mechanical stirrer until it became homogenized. A water bath with a digital thermostat was used to maintain a constant temperature. The bath temperature is initially set to the desired level, and the mixture is stirred until this temperature is reached and becomes homogenized. Next, the contents of the two beakers were mixed and stirring was continued for 10 min. Finally, the synthesized hybrid nanofluid was sonicated using an ultrasonic device (UP400S, Hielscher GmbH) for 10 min to break up any potential aggregation [5]. Throughout all experiments, the concentration of MWCNT particles was maintained at 0.025 wt.%. Four hybrid nanofluids with different concentrations of Ag (0.05, 0.1, 0.2, 0.5 wt.%) were synthesized.

The thermal conductivity of distilled water was measured as the base fluid to validate the thermal conductivity data. The results are consistent with those reported in the literature [16]. Furthermore, the thermal conductivity for each sample was measured twice, and the average value was reported.

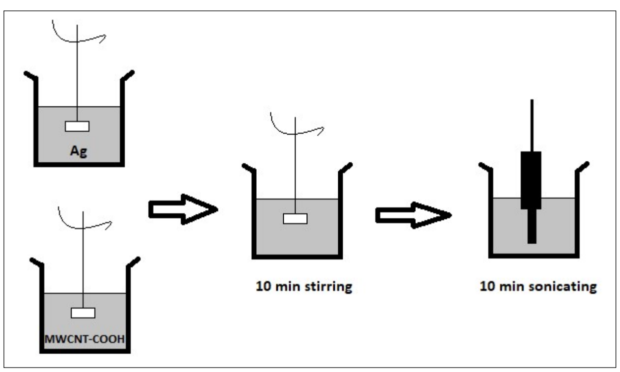

Figure 1. Schematic for synthesis of hybrid nanofluid.

2.3 Analysis

UV-Vis spectrophotometer was used to investigate the dispersibility of nanofluid. The size of nanoparticles and their distribution in the fluid were investigated using the field emission scanning electron microscopes (FE-SEM, TESCAN MIRA3) transmission electron microscopy (TEM, PHILIPS EM 208S) was also carried out for morphological investigation.

2.4 Thermal conductivity measurements

The thermal conductivities of the synthesized hybrid nanofluids were measured in various temperatures in the range of 20–45°C via the transient hot wire (THW) method. It involves a thin wire probe that is heated with a constant current pulse, and the transient response of the wire's temperature is used to calculate the thermal conductivity of the surrounding fluid. The thermal conductivity enhancement can be calculated using the following relation [7]:

$$\eta(\%) = \frac{k_{hnf}-k_{bf}}{k_{bf}} \times 100, \quad (1)$$

where, k_{bf} and k_{hnf} are thermal conductivity of the base and hybrid nanofluid, respectively.

3 Results and Discussion

The UV-Vis spectrophotometer was carried out to confirm the synergistic effect of Ag nanoparticles on MWCNTs. The UV-Vis spectra of MWCNT (0.05 wt.%)/Ag (0.05wt.%) is shown in Fig. 2. The maximum absorption of 1.8 (a.u.) can be seen around 290 nm, which agrees with ref. [9]. Because of the synergistic effect, hybrid nanofluid shows acceptable thermal conductivity and rheological characteristics [17].

The distribution of Ag nanoparticles on MWCNTs is shown in Fig. 3. Ag nanoparticles were distributed uniformly on carbon nanotubes.

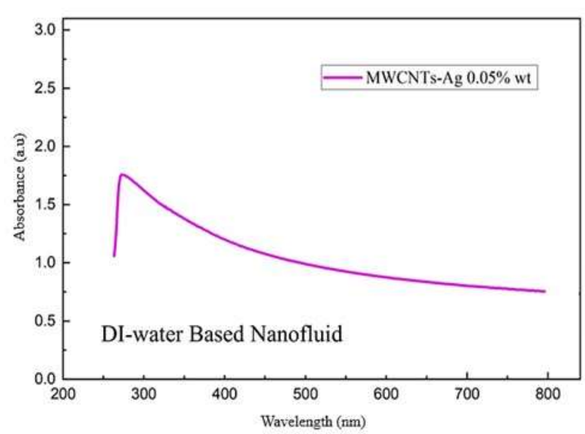

Figure 2. UV spectra of synthesized MWCNT (0.05 wt.%)/Ag (0.05 wt.%) nanofluid.

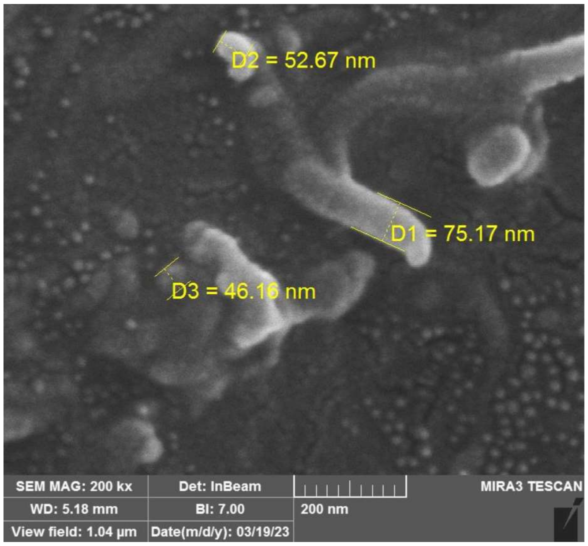

Figure 3. SEM image of MWCNT (0.05 wt.%)/Ag (0.05 wt.%) nanofluid

The UV–vis spectra of the hybrid nanofluids with different concentrations of Ag is shown in Fig. 4. As can be seen, the absorbance can be increased with increasing the concentration of Ag in the nanofluid. The absorbance was decreased by increasing particle aggregation [18]. So, absorbance increases conform nanoparticle dispersion in a nanofluid. Increasing the Ag decoration on MWCNTs improves the dispersibility of nanocomposite. The maximum absorption corresponds to the hybrid nanofluid with a higher Ag concentration (0.5wt%) and increases the concentration of Ag nanoparticles, increasing absorption. The high absorbance of nanofluids can be described due to the presence of Ag nanoparticles. Generally, the high absorbance of Ag between 400 and 800 nm, makes it a good candidate for the synthesis of Ag/ MWCNTs nanocomposite [18].

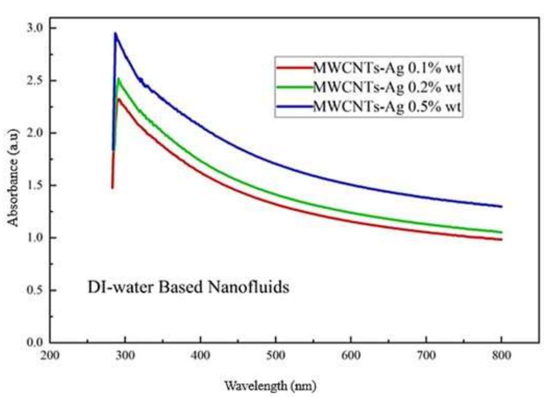

Figure 4. UV spectra of synthesized nanofluid with different Ag concentrations

The thermal behavior of nanofluid is affected by the size and shape of nanoparticles and their distribution. So, the morphology of the synthesized nanofluid and their distribution were investigated by TEM. The TEM images of the synthesized nanocomposite are shown in Fig. 5. TEM with different magnifications was used to confirm the Ag decoration on MWCNT-COOH and also the size and shape of MWCNT and Ag nanoparticles in the base fluid. The spherical Ag nanoparticles decorate the MWCNT cylindrical surface. The cylindrical shape of MWCNTs enhances the thermal conductivity and the spherical shape of Ag nanoparticles causes a low-pressure drop in heat exchangers [9].

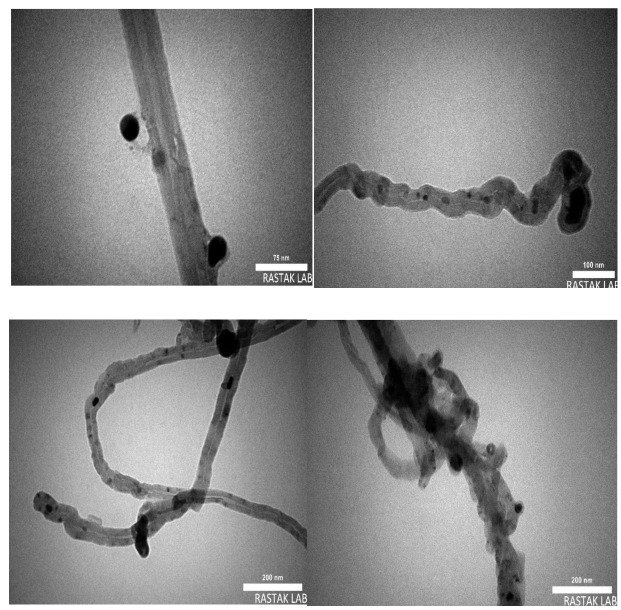

Figure 5. TEM images of MWCNT (0.025)/Ag (0.05) nanofluid with different magnification

The thermal conductivity of the synthesized hybrid nanofluids with various Ag concentrations at different temperatures is presented in Fig. 6. The thermal conductivity of nanofluids increased with increasing temperature at all Ag concentrations. The thermal conductivity can be enhanced linearly with temperature. The viscosity of nanofluid decreases with increasing temperature. As a result, the Brownian motion can be raised [7]. The rising of movement and kinetic energy of molecules due to increasing temperature can enhance thermal conductivity. The thermal conductivity is enhanced by increasing the collisions between surface atom fluid molecules and nanofluid (Brownian motion) [7]. Furthermore, the thermal conductivity can be improved with increasing the Ag concentration. At constant temperature, thermal conductivity increases with increasing the Ag concentration. Because Ag has a high thermal conductivity among metals [5], its presence in nanocomposite increases the thermal conductivity. The cluster of nanoparticles can be created with increasing concentration. These clusters can enhance the heat transfer from solid areas compared to liquid areas [7]. A significant enhancement in thermal conductivity can be obtained by simultaneously increasing the Ag concentration and temperature. The effect of temperature increase on thermal conductivity is lower at a low Ag concentration than at a high Ag concentration due to the high thermal conductivity of Ag. The Ag decoration on MWCNTs and uniform dispersion of nanoparticles cause high thermal conductivity.

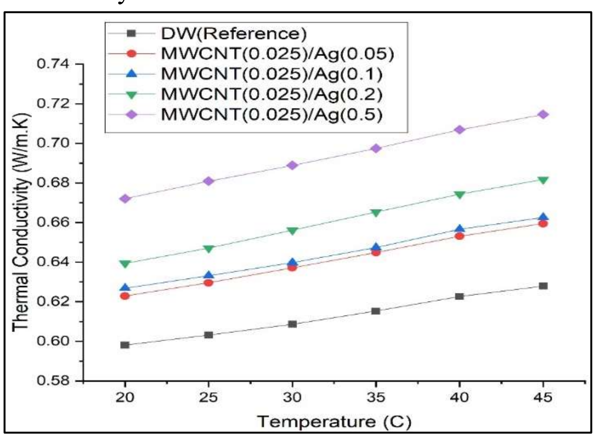

Figure 6. Effect of temperature on thermal conductivity of nanofluid with various concentrations of Ag.

The thermal conductivity enhancement of nanofluid with various concentrations of Ag is shown in Fig. 7. As can be seen, at a constant temperature, the enhancement of thermal conductivity with increasing the Ag concentration is more significant than the enhancement of thermal conductivity with temperature at constant Ag concentration.

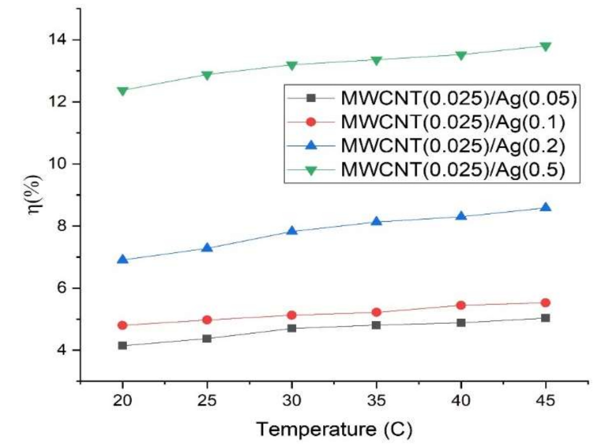

Figure 7. Effect of temperature on thermal conductivity enhancement of nanofluid with various concentrations of Ag.

Stability is crucial in the synthesis of nanofluids; simply improving thermal conductivity is insufficient. It is essential that the synthesized nanofluid also demonstrates high stability. The stability of the synthesized MWCNT/Ag nanofluid was evaluated after more than 90 days. The results indicated that the nanofluid preserved its performance over this period. It is important to note that this stability was achieved without using a surfactant. The presence of surfactants creates thermal resistance between nanoparticles and the base fluid due to micelles formation. Therefore, attaining such stability without surfactants is significant. The UV–vis spectra of the hybrid nanofluids with different Ag concentrations after more than 90 days are shown in Fig. 8. It can be seen that the absorbance is decreased by increasing the concentration of Ag. This is due to the agglomeration of the nanofluids with higher Ag concentrations. Lower Ag densities lead to higher stabilities despite the lower thermal conductivities. Comparing Fig. 2 with Fig. 8 reveals that the maximum absorption in MWCNT-Ag (0.05% wt.) nanofluid remains almost constant after over 90 days.

A comparison of the stability of the lab-made synthesized nanofluid with findings from reported research is shown in Table 2. The synthesized nanofluid demonstrates the highest stability, as shown in Table 2. The only nanofluid with greater stability is from Ref. [20], which incorporates a surfactant and only uses MWCNT. In the current study, stability has been achieved with a nanohybrid formulation without the use of surfactants.

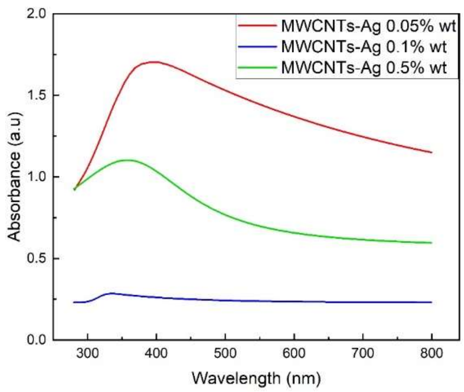

Figure 8. UV spectra of synthesized nanofluid with different Ag concentrations after more than 90 days.

Table 2. Comparison of lab-made hybrid nanofluid with some reported MWCNT nanofluids.

Nanoparticles	surfactant	Stability (day)	Ref.
MWCNT	-	30	[19]
MWCNT	SDS, PVP, AG	>180	[20]
MWCNT	SDBS	45	[21]
TiO_2/Ag	-	<6	[22]
Au/Ag	Gemini	>60	[23]
MWCNT-COOH/Cu	-	45	[2]
MWCNT-COOH/Fe	-	40	[2]
MWCNT-COOH/Ag	-	15	[2]
MWCNT-COOH/Zn	-	0	[2]
MWCNT-COOH/Ag	-	>90	Lab-made

4 Conclusions

The nanocomposite of Ag/ MWCNT was synthesized with different Ag concentrations. The uniform distribution of nanocomposite was confirmed via UV-Vis spectrophotometer and SEM. TEM analysis verifies the decoration of MWCNTs with Ag nanoparticles. The thermal conductivity enhanced linearly with increasing the Ag concentration and temperature. The thermal conductivity can be improved by 15% with increasing the Ag concentration from 0.05-0.5 wt.% and temperature in range of 20-45 C.

The UV-Vis spectrophotometer stability results were conducted after more than 90 days after the initial measurements to investigate the stability of the hybrid nanofluids. Results indicate that the MWCNT/Ag nanofluid maintained its performance for lower Ag concentrations. This stability was achieved without using surfactant in the hybrid nanofluid.

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