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Research Paper

# Thermal conductivity enhancement of COOH-functionalized MWCNTs/ethylene glycol–water nanofluid for application in heating and cooling systems

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## HIGHLIGHTS

- Measurement of thermal conductivity of MWCNTs/EG–water nanofluid.
- Presenting the effects of temperature and nanotubes concentration.
- The Maxwell model failed to predict the thermal conductivity of the nanofluid.
- Suggesting a new correlation to predict the thermal conductivity of the nanofluid.

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## ABSTRACT

In this paper, an experimental investigation on the effects of temperature and nanotubes concentration on the thermal conductivity of MWCNTs/EG–water (40:60 vol.%) nanofluids is presented. The experiments were performed at temperatures ranging from 25 °C to 50 °C and solid volume fraction range of 0–1.0%. They showed that the thermal conductivity ratio enhances with increasing the solid volume fraction and temperature. Moreover, at higher concentration of MWCNTs, the effect of temperature on the thermal conductivity ratio was more tangible. The thermal conductivity measurements also indicated that the maximum enhancement of thermal conductivity of nanofluid was 34.7%, which occurred at solid volume fraction of 1.0% and temperature of 50 °C. The experimental results were compared with data obtained from Maxwell model. Since, this model failed to predict the thermal conductivity of the nanofluid, for engineering applications, using experimental findings, an accurate correlation was presented to predict the thermal conductivity of MWCNTs/EG–water (40:60 vol.%) nanofluids. The maximum value of the deviation was obtained ±1.8% for the proposed correlation.

## 1. Introduction

In most thermal applications, water is used as a working fluid, and ethylene glycol (EG) is an improver, which reduces the freezing point of water. A mixture of water and EG, called antifreeze, is used to achieve freezing-point depression for cold environments. It can also be employed to achieve boiling-point elevation (antiboil) to allow higher coolant temperature. Because of suitable properties of the mixture of water and EG, it is used in internal combustion engines and other heat transfer applications such as HVAC devices and solar collectors. However, this mixture shows lower thermal conductivity compared to that of pure water. Because of its low thermal conductivity, new generations of heat transfer fluids, called nanofluids, have been developed. Nanofluids, which are obtained by dispersing solid nanoparticles (less than 100 nm) in the base fluid, were first introduced by Choi [1]. Many researchers have reported that nanofluids can provide higher thermal conductivity compared to traditional coolants [2–9]. They also showed that the thermal conductivity of nanofluids could be controlled by chemical and physical specifications of nanoparticles and base fluid. Nanofluids have recently been employed in numerous thermal engineering applications [10–22]. Since using appropriate types of nanoparticles as additives to a mixture of water and ethylene glycol is very important to achieve a high heat transfer rate. The thermal conductivity of nanofluids is a key property that should be determined.

As mentioned above, in the winter, the mixture of ethylene glycol and water in various volume percentages is usually used to lower the freezing point of water. Because of many applications of this mixture, several experimental studies were carried out to

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**Table 1**
A summary of existing studies for the thermal conductivity of nanofluids consisted of nanoparticles, ethylene glycol and water.

| Author | Base fluid (EG: water) | Dispersed particles | Maximum enhancement (%) |
|---|---|---|---|
| Vajjha and Das [23] | 60:40 (wt.%) | $Al_2O_3$ | 69 |
| | | ZnO | 48.5 |
| | | CuO | 60 |
| Yu et al. [24] | 45:55 (vol.%) | $Al_2O_3$ | 11.6 |
| Kumaresan and Velraj [25] | 30:70 (vol.%) | MWCNTs | 19.75 |
| Reddy and Rao [26] | 40:60 (wt.%) | $TiO_2$ | 9 |
| | 50:50 (wt.%) | | 10.42 |
| Sahooli and Sabbaghi [27] | 65:35 (vol.%) | CuO | 66 |
| Sundar et al. [28] | 20:80 (wt.%) | $Fe_3O_4$ | 46 |
| | 40:60 (wt.%) | | 42 |
| | 60:40 (wt.%) | | 33 |
| Teng and Yu [29] | 50:50 (vol.%) | MWCNTs | 48.8 |
| Sundar et al. [30] | 50:50 (wt.%) | $Al_2O_3$ | 17.89 |
| | | CuO | 24.56 |
| Suganthi et al. [31] | 50:50 (vol.%) | ZnO | 17.26 |
| Mojarrad et al. [32] | 50:50 (vol.%) | $Al_2O_3$ | 5.5 |
| Syam Sundar et al. [33] | 20:80 (wt.%) | $Al_2O_3$ | 32.26 |
| | 40:60 (wt.%) | | 30.51 |
| | 60:40 (wt.%) | | 27.42 |
| Hemmat Esfe et al. [34] | 40:60 (vol.%) | CuO | 36.97 |
| Hemmat Esfe et al. [35] | 40:60 (vol.%) | MgO | 35 |
| Hemmat Esfe et al. [36] | 40:60 (vol.%) | Cu-$TiO_2$ | 44 |

determine the thermal conductivity of nanofluids consisting of nanoparticles, water and ethylene glycol. A summary of these studies is presented in Table 1. In the aforementioned studies, water and ethylene glycol were mixed in different proportions and the nanoparticles were dispersed into the mixture. However, these studies confirm that adding nanoparticles to a mixture of water and ethylene glycol can enhance its thermal conductivity.

A review of previous studies on nanofluids as a coolant [37–41] showed that nanofluids could be a suitable alternative for traditional coolants in the engine cooling system. Hence, it can be found that adding nanoparticles to standard cooling liquids can improve the cooling rate of radiator in the engine cooling system, thus leading to a better aerodynamic feature for the design of an automotive car frontal area. Moreover, these studies reported that the use of nanofluids, as a coolant, leads to diminishing the drag coefficient, reducing parasitic losses, improving the operation of water pumps, reduction of friction and wear, and enhancing fuel efficiency.

The literature survey reveals that there are a few works on the thermal conductivity of carbon nanotubes (CNTs) dispersed in binary mixtures of water and ethylene glycol. On the other hand, CNTs have a high thermal conductivity, low specific gravity, and high aspect ratio as compared to CuO, $Al_2O_3$, $TiO_2$, MgO, $Fe_3O_4$ and ZnO nanoparticles. Because of excellent thermal properties of CNT nanofluids, in the current research, thermal conductivity of COOH-functionalized MWCNTs/EG–water (40–60%) has been determined experimentally. Moreover, due to lack of a model for predicting the thermal conductivity of this nanofluid, a new correlation is proposed as a function of the solid volume fraction and temperature for engineering applications using experimental data.

## 2. Experimentation

### 2.1. Preparation of samples

Among nanofluids experiment steps, nanofluids preparation is the first important step, and a proper dispersion of nanoparticles in the base fluid is necessary. In this way, appropriate mechanisms such as magnetic stirring and sonication can be employed to achieve the stability of the suspension against nanoparticles sedimentation. In addition, two techniques could be used to achieve stable nanofluids containing carbon nanotubes that include using a surfactant such as Arabic gum, and the functionalization of the carbon nanotubes [42]. Adding a surfactant may have unfavorable effects on the thermal conductivity of the samples; therefore, employing functionalized carbon nanotubes seems more appropriate.

In this work, a mixture of 60 vol.% water and 40 vol.% ethylene glycol (Merck product, Germany) was used as the base fluid. COOH-functionalized multi-walled carbon nanotubes (MWCNTs) with solid volume fractions of 0.025 vol.%, 0.05 vol.%, 0.1 vol.%, 0.2 vol.%, 0.4 vol.%, 0.75 vol.% and 1.0 vol.% were added to the base fluid by using a two-step method. The weight of MWCNTs for preparing of samples was measured by using a sensitive electronic balance with an accuracy of 1 mg. It should be noted that at the higher solid volume fraction than 1%, clustering phenomenon was observed, which leaded to deposition and sedimentation of nanotubes, and nanofluids was unsuspended. The chemical and physical properties of water and ethylene glycol have been listed in Table 2. The properties of COOH-functionalized MWCNTs also have been described in Table 3. In order to obtain a characterization of the sample, the structural properties of the dry multi walled carbon nanotubes were measured by using X-ray diffraction (Fig. 1).

In the present experiment, to prepare stable functionalized MWCNTs/EG–water nanofluids, after magnetic stirring for 2.5 h, the suspensions were exposed to an ultrasonic processor (Hielscher Company, Germany) with the power of 400 W and frequency of 24 kHz for 6 h. This method, which leads to attain a stable suspension and a uniform dispersion, was used in order to break down the agglomeration between the particles. Moreover, the photograph of MWCNTs, ethylene glycol and COOH-functionalized MWCNTs/EG–water nanofluid are displayed in Fig. 2.

**Table 2**
Chemical and physical properties of water and ethylene glycol.

| Parameter | Value | |
|---|---|---|
| | Water | Ethylene glycol |
| Chemical formula | $H_2O$ | $C_2H_6O_2$ |
| Molar mass | 18.01528 (g/mol) | 62.07 (g/mol) |
| Appearance | Almost colorless, transparent | Clear, colorless liquid |
| Odor | Odorless | Odorless |
| Density | 998.21 (kg/m$^3$) | 1113.2 (kg/m$^3$) |
| Melting point | 0.00 (°C) | −12.9 (°C) |
| Boiling point | 100 (°C) | 197.3 (°C) |
| Thermal conductivity (@20 °C) | 0.6 (W/m K) | 0.244 (W/m K) |
| Viscosity (@20 °C) | 1 (cP) | 16.1 (cP) |

**Table 3**
Properties of COOH-functionalized MWCNTs.

| Parameter | Value |
|---|---|
| Purity | >97% |
| Content of –COOH | 2.56 (wt.%) |
| Color | Black |
| Outer diameter | 5–15 (nm) |
| Inner diameter | 3–5 (nm) |
| Length | ~50 (μm) |
| Thermal conductivity | ~1500 (W/m K) |
| True density | ~2100 (kg/m$^3$) |