An experimental study on the influence of functionalized carbon nanotubes CNT Taunit series on the thermal conductivity enhancement

A J Ali¹-² and E N Tugolukov¹

¹Technology and Methods of Nano Products Manufacturing, Tambov State Technical University, 106 Sovetskaya Street, 392000 Tambov, Russian Federation
²Department of Biomedical Engineering, University of Technology, Iraq

¹E-mail: 10678@uotechnology.edu.iq

Abstract. This paper aims to determine the thermal conductivity for two types of functionalized carbon nanotubes (FCNT “Taunit M”) nanofluids. FCNT₁ and FCNT₂ have been used to enhance the thermal conductivity of nanofluids. Six concentrations of 0.01, 0.02, 0.03, 0.05, 0.07, 0.1 wt.% loading of FCNT₁ and three concentrations of 0.01, 0.05, 0.1 wt.% loading of FCNT₂ have been used in this experiment. The experiments were achieved at temperatures 40°C. The technique for measuring thermal conductivity was described and manufactured at Tambov State Technical University. As a result of the study, the effect of increasing concentrations of FCNTs in the aqueous medium on thermal conductivity was presented. The relationship was nonlinear in FCNT₁. The maximum enhancement thermal conductivity was 11.6 and 7.1% loading FCNT₁ and FCNT₂ respectively, which achieved at a weight fraction of 0.05 and 0.1 % respectively. Finally, the latest researches in this field were presented for comparison in the results obtained.

1. Introduction

The enhancement of thermal conductivity in conventional heat transfer fluids was an engineering challenge and problem. One of the ways to solve this problem is to take aiming measures to increase the values of thermal conductivity by adding nanoparticles to traditional heat transfer fluids, which leads to increase in the overall heat transfer process. One of the results of this addition to heat transfer fluid is the appearance of nanofluid. Therefore, there are numerous numerical and experimental studies concentrated on nanofluids [1-3]. Nanofluids are engineered by a mixture of the traditional heat transfer fluids like oils, distilled water, fat, Ethylene glycol, and others with nanoparticles 100 nm such as Cu, CuO, Si, MWNT, SWNT, etc. But one of the problems in the nanofluid, which drew the attention of workers in this field is the agglomeration and sedimentation of nanoparticles after various time periods. Therefore, the best improvement which can be obtained is: dispersed uniformly in host-based fluids and suspended stably [4]. Several methods have been used to avoid agglomeration and sedimentation of nanoparticles and to obtain a stable suspension: chemical and physical methods by adding surfactants and using ultrasonic at different frequencies respectively; electrical method by controlling the pH [5, 6]. Carbon nanotubes for nanofluids have been attracted the attention of various researchers due to their advantage such as high thermal conductivity that is higher in comparison with other nanoparticles. It is a result of the aspect ratio which is an important factor in improving thermal
conductivity [7, 8]. Carbon nanotubes have thermal conductivity reaching (2000-3500) W/m.K [9]. Carbon nanotube exists as the single type particle such as single (SWCNTs), multi-walled (MWCNTs) and double (DWCNTs) structures or like hybrid nanoparticles recently appeared [10].

In this research thermal conductivity of functionalized carbon nanotubes “Taunit M” (FCNT₁ and FCNT₂) in the base fluid (distilled water) was measured. The latest researches in this field for the same type of nanoparticles were analyzed for comparison of the results obtained.

2. Experimental part

2.1. Chemicals
There are two types of functionalized carbon nanotubes “Taunit M” (FCNT₁ and FCNT₂) were produced for the improvement of thermal conductivity in the water. The difference between (FCNT₁) and (FCNT₂) is the growth at different time periods on the catalyst, where it was 40 minutes for FCNT₁ and 5 minutes for FCNT₂ in the reactor CVD. Carbon nanostructured materials were manufactured at (NanoTechCenter Ltd) in Tambov Region, Russia [11]. The functionalized CNTs were prepared by using the traditional method of chemical oxidation of CNT with sodium hypochlorite [12, 13].

2.2. Measurement of thermal conductivity of nanofluid and stability
The manufacturers certified measuring equipment that provides high measurement accuracy is complex and expensive. In this regard, the development of experimental methods for determining the thermal conductivity of liquids, including nano-modified, is currently continuing. The transient hot-wire (THW) method is widely used, especially by device KD2 thermal property analyzer [14]. The experimental model of thermal conductivity measurement is manufactured in this research at Tambov state technical university as shown in figure 1. It consists of a cup made of a material that has low thermal conductivity, which removable module is mounted. Also, the module contains a heater and temperature sensors 4 and 5 located along the axis of the cup.

![Figure 1. Scheme of the experimental setup: 1- cup; 2- which removable module is mounted; 3- heater; 4, 5 -the temperature sensors; 6-temperature sensor is installed on a cooled metal base; 7- cooled metal base ; 8- heat-insulating coating.](image)

The functionalized carbon nanotubes “Taunit M” nanofluids have high stability in time, as can be seen in figures 2 and 3. In order to ensure accuracy, the measurement was conducted for 3 times for one sample under the same experimental conditions. The rig was calibrated by using distilled water in the considered temperature range before the start of measuring. The error rate did not exceed and has a tolerance accuracy of ±5%. Operates according to principle a somewhat similar is based on transient hot-wire THW. The values of nanofluids effective thermal conductivity at temperature 40 °C have
been provided. In order to evaluate the stability of nanofluids, the samples have been maintained under static conditions and standard atmospheric temperature for six months. It was observed neither agglomeration of nanoparticles nor sedimentation during this period. This is a good indicator of nanoparticle stabilization in comparison with other researches.

The main properties and SEM images of the functionalized carbon nanotubes (FCNT “Taunit M”) are presented in table 1 and figure 4 respectively.

Table 1. Properties of functionalized carbon nanotubes “Taunit M”.

| Parameter                          | Value                     |
|------------------------------------|---------------------------|
| Inner diameter                     | 4-8 nm                    |
| Outer diameter                     | 8-15 nm                   |
| Length, μm                         | 2 and more                |
| Bulk density, g / cm               | 0.03÷0.05                 |
| Total amount of impurities %,      | up to 5                   |
| (after purification)               | up to 1                   |
| Specific geometrical surface, m²/g | 180-200                   |
| Thermal stability (°C)             | up to 600                 |
| Color                              | Black                     |

Figure 2. Samples of FCNT₁ and FCNT₂ “Taunit M” nanofluids.

Figure 3. Samples of FCNT₁ and FCNT₂ “Taunit M” nanofluids after six month.

Figure 4. SEM images of the functionalized carbon nanotubes "Taunit M" [15].
Two types of functionalized carbon nanotubes “Taunit M” were evaluated in this experiment. Six concentrations of 0.01, 0.02, 0.03, 0.05, 0.07, 0.1 wt.% loading of FCNT1 and three concentrations of 0.01, 0.05, 0.1 wt.% loading of FCNT2 have been used. The experiment was achieved at temperature 40°C. The maximum improvement of thermal conductivity was 11.6% at 0.05 wt.% loading of FCNT1, that means to achieve an increase in the thermal conductivity of water from 0.625 to 0.71 W/m.K, and for the second type 7.1% enhancement at 0.1 wt.% loading of FCNT2, it means to achieve an increase in the thermal conductivity of water from 0.625 to 0.67 W/m.K. The relationship was nonlinear in FCNT1. The thermal conductivity improvement of FCNT2 remained constant from 0.01 to 0.05 wt.%, then the thermal conductivity rose to 7.1% improvement at 0.1 wt.%. The relationship between thermal conductivity and concentration of the studied FCNT is presented on figures 5 and 6.

It is known that thermal conductivity increase with increasing temperature and concentration. However, this is not always as the higher concentration might affect the dispersion of nanoparticles in the water with the absence of a surfactant. The dispersion / stability of nanoparticles is the most factor importance in enhancing thermal conductivity. In this paper, the improvement of thermal conductivity decreases at 0.07 and 0.1 wt.% loading for FCNT1, due to agglomeration in our solution. The reason was the low volume of solution and due to the low density of CNT, the bulk volume of CNT will be high which will be shrinkage in the solution and losing its stability.

**Figure 5.** Relationship between increased thermal conductivity VS Concentration FCNT2.

**Figure 6.** Relationship between increased thermal conductivity Vs Concentration FCNT1.

3. Comparison between FCNT1 nanofluid and other functionalized carbon nanotube nanofluids on enhancement thermal conductivity

The latest researches in carbon nanotube nanofluids were analyzed to compare obtained experimental results for the FCNT1 (table 2). Taunit FCNT2 has been neglected due to the lower enhancement in comparison with FCNT1 type.

According to the literature review of modern studies in various CNT nanofluids Shamaeil et al. [16] have tested 0.02, 0.05, 0.075, 0.1, 0.25 and 0.6 % solid volume fraction double-walled carbon nanotubes (DWCNTs) in ethylene glycol (EG) for thermal conductivity improvement and showed 24.9 % enhancement of 0.6 vol%. Harandi et al. [17] have examined the thermal conductivity of FMWCNTs–Fe3O4 in EG at 0 to 2.3 % volume fraction. The maximum improvement of thermal conductivity was 30%, which was achieved at 2.3 vol%. In the paper of Soltanimehr et al. [18] the highest improvement in thermal conductivity of the MWCNTs/Ethylene glycol EG (40 vol.%) and distilled water (60 vol.%) found to be 34.7% enhancement at 1.0 vol.% loading. Manasrah et al. [19] have reported the effects of pristine carbon nanotubes and functionalization CNTs with polyethylene glycol (MWCNTs-PEG) by using Fischer esterification method to show their dispersion in base fluid.
with various concentrations of 0.01 wt.%, 0.05 wt.% and 0.1 wt.% without using any surfactants. The maximum improvement of thermal conductivity was 5.77% and 19% at 1 wt.% loading of pure CNT and functionalized MWCNTs respectively. Esfe et al. [20] studied the thermal conductivity of (SiO$_2$-MWCNT/EG) hybrid nanofluid at 0.025 to 0.86 vol.% and showed an enhancement of up to 20.1% more than base fluid thermal conductivity at 0.86 vol.%. The thermal conductivity of CuO-SWCNTs in EG40% - water 60% nanofluid with 0.02 to 0.75 vol.% has been investigated by Rostamian et al. [21]. It has been noted the thermal conductivity increase by 36.2% at 0.75% volume fraction. SWCNT–Al$_2$O$_3$ in EG (hybrid nanofluid) at volume fractions of 0.04, 0.08, 0.15, 0.3, 0.5, 0.8, 1.5 and 2.5 have been experimentally investigated by Esfe et al. [22]. They observed increase in the thermal conductivity reaches 41.2% suspensions at a volume fraction of 2.5%. In other paper Esfe et al. [23] have investigated the influence of functionalized single walled carbon nanotubes (FSWCNTs) in the base fluid Ethylene Glycol suspension at 0.02, 0.05, 0.075, 0.1, 0.25, 0.5 and 0.75% volume fraction. It was noted maximum enhancement 45% for 0.75 vol%. Mirbagheri et al. [24] have investigated the influence of functionalized multi-walled carbon nanotubes (FMWCNTs) in the base fluid of EG-water (20:80 vol.%) containing concentrations 0.025 to 0.8 vol.% loading. It was observed 27.3% enhancement in thermal conductivity for 0.8 vol.% concentration of FMWCNTs. Omrani et al. [25] investigated MWCNTs with different geometrical characteristics in water based nanofluids containing 0.05 vol.%. The maximum improvement of thermal conductivity reached to 36% at 45 °C in comparison to the water.

**Table 2.** A literature review on modern studies in various CNT-nanofluids.

| Investigator          | Particles Hybrid particles | Base fluids | Concentration (%) | Maximum enhancement (%) | T (°C) | year |
|-----------------------|-----------------------------|-------------|-------------------|--------------------------|--------|------|
| **our research**      | FCNTs                       | water       | 0.05 wt.% (0.03 vol.%) | 11.6%                    | 40 °C  | 2019 |
| Omrani et al.         | FMWCNTs                    | DIW         | 0.05 vol.%         | 36%                      | 45 °C  | 2019 |
| Mirbagheri et al.     | FMWCNTs                    | Water-EG (80-20) | 0.8 vol.% | 27.3%                    | 50 °C  | 2018 |
| Esfe et al.           | FSWCNTs                    | EG          | 0.75 vol.%         | 45%                      | 50 °C  | 2018 |
| Manasrah et al.       | FCNT+PEG                    | water       | 1 wt.% (0.6 vol.%) | 19%                      | 35 °C  | 2017 |
| Esfe et al.           | SiO$_2$-MWCNT (30-70%)     | EG          | 0.86 vol.%         | 20.1%                    | 50 °C  | 2017 |
| Rostamian et al.      | CuO-SWCNTs (40:60)         | EG water    | 0.75 vol.%         | 36.2%                    | 50 °C  | 2017 |
| Esfe et al.           | WCNT–Al$_2$O$_3$ (30-70%)  | EG          | 2.5 vol.%          | 41.2%                    | 50 °C  | 2017 |
| Shamaeil et al.       | FDWCNTs                    | EG          | 0.6 vol.%          | 24.9%                    | 52 °C  | 2016 |
| Harandi et al.        | FMWCNTs                    | EG          | 2.3 vol.%          | 30%                      | 50 °C  | 2016 |
| Soltanimehr et al.    | FMWCNTs                    | EG-water (40:60) | 1.0 vol.% | 34.7%                    | 50 °C  | 2016 |

It remains to be known that stability and the economic side play an equal role in enhancement thermal conductivity nanofluids. In this research it has been obtained an improvement in thermal conductivity taking into account the economic side where the concentration of FCNT was the least in comparison with other researches and the nanofluids have high stability. Because the cost of adding
carbon nanotubes in the base fluid is high, so the low concentration is better on the economic side. Finally, we have concluded from this analysis and results that the carbon nanotubes lead to enhance in thermal conductivity. Therefore, the urgent need proposed for future works is to make many experimental studies on the thermal conductivity of CNT nanofluids and Hybrid CNT nanofluids in various basal fluids with the possibility to obtain valuable and new results.

4.Conclusions
The thermal conductivity of functionalized carbon nanotubes “Taunit M” (FCNT₁, FCNT₂) in the base fluid (distilled water) was measured for these two types. The first type (FCNT₁) achieved an improvement of thermal conductivity, especially in the 0.05 wt.%, reaching 11.6%, and the relationship was nonlinear with a concentration of this type, where there was a decrease in improved thermal conductivity reaches to 6.1% at 0.1 wt.%. The maximum enhancement of 7.1% at 0.1 wt.% was shown in the second type FCNT₂. The thermal conductivity measuring device was manufactured at Tambov State Technical University. Calibration has been implemented on a device by using distilled water and the error rate ranged from ± 5%. The device can be developed in the future to be more accurate and reliable. The third part of this study was a comparison between the result of this research and other recent researches result on each of CNTs and hybrid CNT nanofluids. It can be concluded that the improvement in thermal conductivity with economic importance in our research result was good. Finally, we need to develop these results.

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