



## An Experimental Study on the Thermal Conductivity of Carbon Nanotubes/Oil

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### ABSTRACT

In the present work, the thermal conductivity coefficients of nanoparticle-oil suspensions for two types of carbon nanotubes, single-walled (SWNTs) and multi-walled (MWNTs) carbon nanotubes at 0.1, 0.2 and 0.3 wt.% were measured by a modified transient hot wire method (KD2-pro thermal property meter). Results showed that the thermal conductivity of suspension containing single-walled carbon nanotubes is higher than that of suspension containing multi-walled carbon nanotubes. It was also observed that the thermal conductivity coefficients of both nanofluids increase with increasing temperature.

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## 1. INTRODUCTION

Numerous researchers have been investigating better techniques to enhance the thermal performance of heat transfer fluids. One of the methods used is to add nano-sized particles of highly thermally conductive materials like carbon, metal, and metal oxides into the heat transfer fluid to improve the overall thermal conductivity of the fluid. The dispersion or suspension thus obtained is called as a nanofluid.

Zhu et al. [1] demonstrated that the stability and thermal conductivity of  $\text{Al}_2\text{O}_3$ /water nanofluids are highly dependent on pH values and the different SDBS (sodium dodecyl benzene sulfonate) dispersant concentrations of Nanosuspensions. Xuan and Li [2] and Yu et al. [3] have demonstrated that the heat transfer properties of transformer oil can be improved by using nanoparticle additives. The effect of temperature and nanoparticles concentration on the thermal conductivity of Cu and Al-Water nanofluids was investigated by Tajik Jamal-Abad and Zamzamin [4]. Experimental results show that the thermal conductivity of Cu/Water nanofluid is more than that of

Al/Water nanofluid. Moreover, classic models have failed to predict the thermal conductivity of nanofluids.

Much research has been published on thermal conductivity for metal oxide nanofluids, but comparatively less for CNT nanofluids [5, 6]. One of the first works involving CNT nanofluids was by Choi et al. [7]. They measured the effective thermal conductivity of MWCNTs dispersed in synthetic poly( $\alpha$ -olefin) oil and reported a thermal conductivity enhancement of 160% by adding 1.0 vol % nanotubes in oil. Subsequently, data was published by Xie et al. [8] where enhancements were reported for water, ethylene glycol and decene as base fluids. Assael et al. [9, 10] data focused on aqueous MWCNT nanofluids with SDS (sodium dodecyl sulfate) and CTAB (Cetyl Trimethyl Ammonium Bromide) as dispersants. The maximum thermal-conductivity enhancement observed by Xie et al. [8] was only 20% for 1vol.% nanotubes in decene and that observed by Assael et al. [9] was 38% for 0.6% CNTs in water. Wen and Ding [11] published data using SDBS as the dispersant. Their results were comparable to those of Xie et al. [8] and Assael et al. [9] and proposed differences in the interfacial resistances and thermal conductivities of carbon nanotubes used in these studies as the main reasons for the observed discrepancies with respect to Choi et al. [7]. Phuoca et

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al. [12] studied thermal conductivity, viscosity, and stability of nanofluids containing multi-walled carbon nanotubes (MWCNTs) stabilized by cationic chitosan. The measured thermal conductivity showed an enhancement from 2.3% to 13% for nanofluids—that contained from 0.5 wt% to 3 wt% MWCNTs (0.24 to 1.43 vol %). Experimental results on effective thermal conductivity and specific heat capacity of ion nanofluids as a function of temperature and concentration of multi-wall carbon nanotubes in several ionic liquids are presented by Nieto de Castro et al [13].

In this work, thermal conductivity of CNT/oil nanofluids are investigated in different concentrations. The nanotubes were produced by chemical vapor deposition (CVD) process and thermal conductivity measure via transient hot-wire method (KD2-pro). Finally, the discrepancy between thermal conductivity of nanofluids will be discussed.

## 2. SAMPLE PREPARATION

Carbon nanotubes were synthesized by catalytic decomposition of methane in hydrogen over Co-Mo/MgO catalysts at 800–1000 °C [14] Figure 1 shows a transmission electron microscope (TEM) image of CNTs. The average diameter of Single-Walled and Multi-Walled Carbon Nanotubes is 2-3 and 10 nm respectively, and the length is not more than 10  $\mu$ m. Nanofluids are prepared by a two step process. A deficiency of this method is the tendency of nanopowder to agglomerate during storage and dispersion in the base fluids. Mechanical mixing and ultrasonic bath (Ms Hielscher model UP400S) can be used to break up agglomerates and give more uniform dispersions. To make the nanoparticles more stable and make them remain more dispersed in water, ultrasonicator is used. Sonication was done for 1 hour before measuring any thermo-physical property of the nanofluids. Nanofluids were found very stable and the stability lasted over a week; some sedimentation was found for mass concentrations after two days; however, it was still long enough for the experiments.

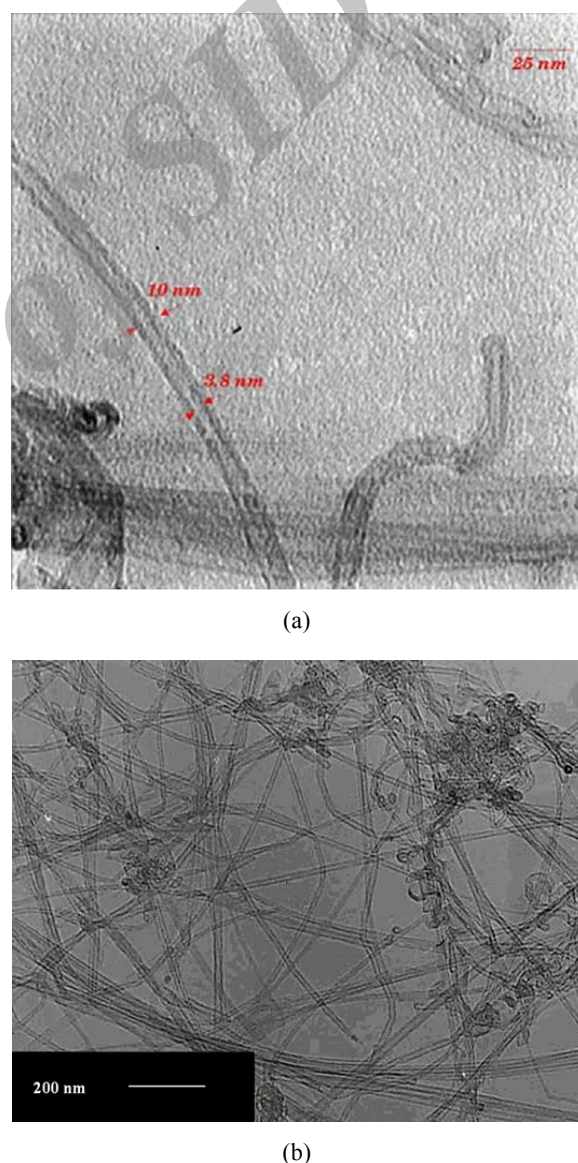
## 3. EXPERIMENTAL EQUIPMENT AND PROCEDURE

The thermal conductivity was measured by using a KD 2 Pro thermal properties analyzer from Decagon devices, Inc. The instrument had a probe of 60 mm length and a 1.3 mm diameter and included a heating element, a thermo-resistor and a microprocessor to control and measure the conduction in the probe. The instrument had a specified accuracy of 5%. The measurements were taken under different temperatures. A number of measurements were taken for each sample and a mean of only those measurements with 'R2' value,

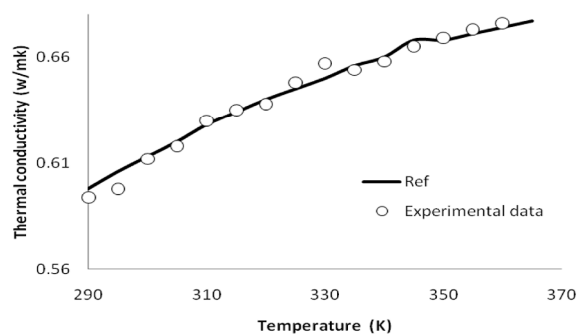
square of correlation coefficient, greater than 0.9995 were considered. The instrument was based on the working principle of a transient hot wire method.

## 4. EXPERIMENTAL RESULTS

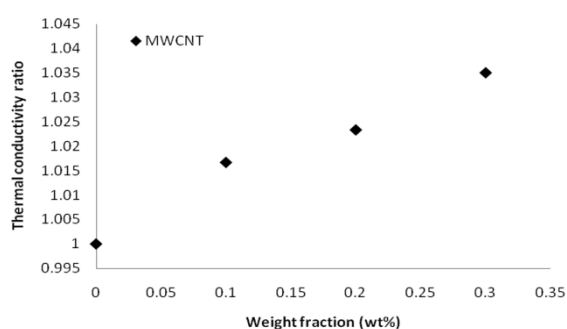
Validation of the apparatus and procedure was done by comparing results for distilled water with available correlations data in literature [15] Figure 2 shows that good agreement is found between data obtained with the thermal properties analyzer and available correlation.



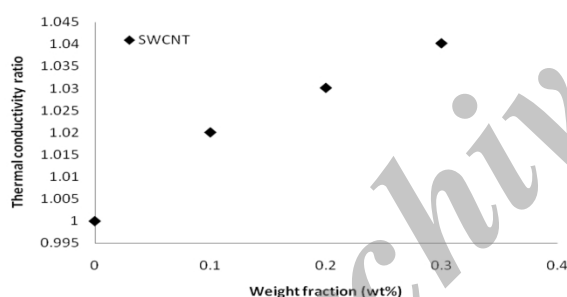
**Figure 1.** TEM image of RIPI (Research Institute Of Petroleum Industry)-MWNTs, (A) MWNT, and (B) SWNT.



**Figure 2.** Validation of thermal properties analyzer KD2 by distilled water.

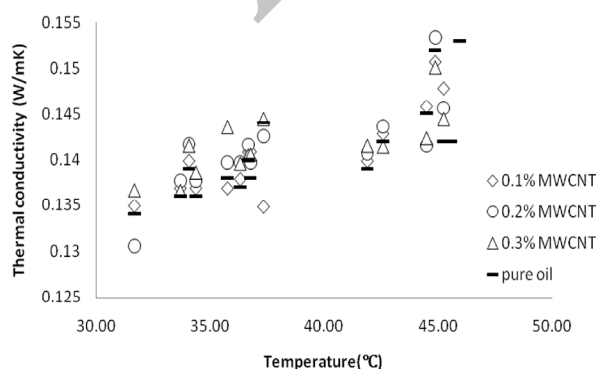


(a)



(b)

**Figure 3.** Thermal Conductivities of (a) MWCNT/oil and (b) SWCNT/oil nanofluids as function of weight fraction.



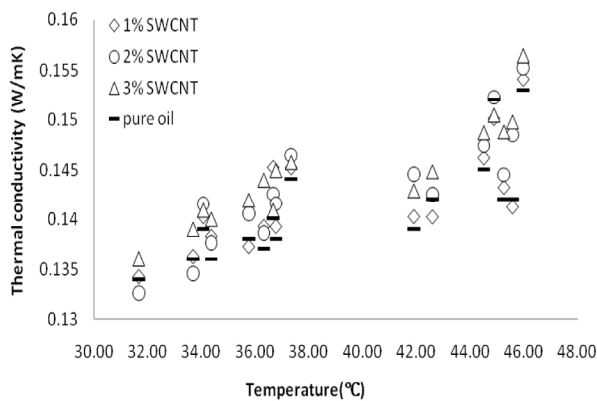
**Figure 4.** Thermal conductivity of MWCNT/oil nanofluids at different concentrations versus temperature

**TABLE 1.** Enhanced thermal conductivities of CNTs/ oil nanofluid.

Weight fraction	Thermal conductivity increase ratio (%)	
	MWCNT/oil	SWCNT/oil
0.1	1.6	2
0.2	2.3	3
0.3	3.4	4

Figures 3 (a) and (b) show the thermal conductivity enhancements of MWCNT/oil and SWCNT/oil nanofluids as a function of weight fraction of CNTs. The results clearly show that SWCNT/oil has higher thermal conductivity than MWCNT/oil nanofluid. For SWCNT and MWCNT nanofluids at a weight fraction of 0.1 wt%, thermal conductivity enhancements of up to 2 and 1.6% are observed respectively. On the other hand, maximum enhancement is observed for SWCNT/oil, thermal conductivity is enhanced by 4% at a volume fraction of 0.3 wt.%. Conductivity of CNTs nanofluid is enhanced approximately linearly with the volume fraction of CNTs. The results are illustrated in Table 1.

Figure 4 shows the absolute thermal conductivity data obtained using KD 2 Pro thermal properties analyzer. Measurements are taken for each sample under different temperature conditions. It was seen that the thermal conductivity of the nanofluid samples, first increased slightly with temperature and after 36 °C, it varied non-linearly with temperature. One of the suggested reasons behind this phenomenon is the increased Brownian motion effect. A similar pattern can be seen for thermal conductivity of SWCNT/oil nanofluids versus temperature (Figure 5). Thermal conductivity increases with temperature for all weight fractions. For example, thermal conductivity goes up from 0.1373 W/mK for 0.1 wt% to 0.14 and 0.141 W/mK for 0.2 and 0.3 wt%, respectively. The reason behind thermal conductivity enhancement in carbon nanotube dispersions is still not completely understood. Studies have indicated that nanotubes conduct current and heat ballistically or in fast diffusive manner [16]. The ballistic conduction is associated with the large phonon mean-free path in nanotubes. There is evidence that an organized solid-like structure of a liquid at the interface is governing factor in heat conduction from a solid wall to an adjacent liquid [17]. Additionally, Brownian motion of nanoparticles is another reason for increasing thermal conductivity of nanofluids at elevated temperatures. When temperature is increased, the viscosity of base fluids is decreased and the Brownian motion of nanoparticles is consequently increased. It has been postulated that convection like effects are induced by Brownian motion which results in increased conductivities.



**Figure 5.** Thermal conductivity of SWCNT/oil nanofluids at different concentrations on temperature

## 5. CONCLUSION

The aim of the present work was to study thermal conductivity of CNTs nanofluids. The heat transfer oil was selected as the base fluid. Single-walled carbon nanotubes and multi-walled carbon nanotubes were added to the base fluid at 0.1, 0.2 and 3% weighted-average concentrations. The study included the use of a KD2-pro to measure the thermal conductivity of the three nanofluids with different nanotubes loadings. The highlights of the study could be stated as following:

- ❖ SWCNT/oil has higher thermal conductivity compared to MWCNT/oil nanofluid
- ❖ Maximum enhancement is observed for SWCNT/oil, thermal conductivity is enhanced by 4% at a volume fraction of 0.3 wt.%
- ❖ Conductivity of CNTs nanofluid is enhanced approximately linearly with the volume fraction of CNTs

Thermal conductivity increases with temperature for all weight fractions. For example, thermal conductivity goes up from 0.1373 W/mK for 0.1 wt% to 0.14 for SWCNT/oil.

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### TECHNICAL NOTE

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درکار حاضر، ضرایب هدایت حرارتی سوسپانسیون‌های نانوذره-روغن برای دو نوع نانوتیوب کربنی تک دیواره و چند دیواره در درصد های وزنی ۰/۱، ۰/۲ و ۰/۳ با روش سیم داغ اصلاح شده (D2-pro thermal property meter) اندازه گیری شد. نتایج نشان داد که هدایت حرارتی سوسپانسیون حاوی نانولوله های کربنی تک دیواره بیشتر از نانولوله های کربنی چند دیواره است. همچنین، مشاهده شد که ضرایب هدایت حرارتی هر دو نانوسیال با افزایش دما افزایش پیدا می کند...

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