Synthesis and Enhancement of Thermal Conductivity of Surfactant Free MWCNTs-Jatropha Oil-based Nanofluid

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Abstract. Thermal conductivity enhancement of multi-walled carbon nanotubes (MWCNTs) based nanofluids received the attention of many researchers due to its remarkable thermal properties. However, the synthesis of surfactant-free multi-walled carbon nanotubes based nanofluids with higher dispersion stability to maintain a trade-off between its dispersion stability and thermophysical properties is still a challenge. In this research, a surfactant-free multi-walled carbon nanotube and Jatropha seed oil-based nano-dispersion are prepared via one-step method and subjected to experimental determination of thermal conductivity within the temperature range of (25 °C - 65 °C) and nanoparticle volume fraction range of (0.2 wt.% - 0.8 wt.%). The prepared nanofluid found to be highly stable for long time and its thermal conductivity enhancement was found to be 6.76%.

1. Introduction
Nanofluids was first synthesized by the Choi in 1995 [1]. They have obtained a nano-dispersion of nanoparticles (< 100nm) in conventional base fluids such as water, ethylene glycol, fuel oil, etc.). The enhanced thermo-physical properties of nanofluids have attracted many researchers for great potential in heat transfer applications. Even a fraction of specific nanoparticles dispersed in the base fluid can enhance its thermo-physical properties and makes nanofluid an ideal candidate in the field of heat transfer engineering [2, 3]. Because of enhanced thermo-physical properties of nanofluid, they have been utilized in various industrial applications including industrial fluid systems, transportation, thermal management system, cooling technologies, lubricant fluid, magnetic fluid, and heat transfer fluid [4-6]. Furthermore, air
conditioning, transportation, power generation, heat pipes, solar collectors, defense, electronic cooling, space, biomedicines, lubricating agent, corrosion inhibitors, and nuclear systems cooling [7, 8].

During last two decades, various nanoparticles in different forms (of disk, particle, tube, fiber, sheet, etc.) including nitrides [9], metals [10], diamonds [11], carbon nanotubes [12-15], oxides [16], carbon black [17], carbon nanofibers [18], graphene [19], graphene oxide [19], graphite black [20, 21], and hybrid [22, 23] have been utilized for the synthesis of nanofluids to enhance thermal performance. Among these materials, carbon-based materials especially carbon nanotubes found to be promising candidate because of its excellent thermal properties. To date, a number of nanofluids have been reported in literature i.e. CNTs such as water and antifreeze containing CNTs nanoparticles [24], S-SWNTs-water, L-SWNTs-water, [25, 26], silver decorated CNTs-water [27], copper oxide surface modified CNTs-water nanoparticles [28], graphene based MWCNTs-ethylene glycol [29], hexylamine coolant modified MWCNTs-transformer oil [30], functionalized MWCNTs-ionic liquids [31], MWCNTs-imidazolium based ionic liquids [32], CNTs-deionized water [33], Fe3O4-MWCNTs-distilled water [34], CNTs- poly-alpha-olefin (PAO) [35], Cu-CNTs-deionized water and Au-CNTs-deionized water [36], Cu-MWCNTs-ethylene glycol-water [22], Al2O3-MWCNTs-water [37], MWCNTs-Turbine Oil [38], MWCNTs-Engine Oil [39], MWCNTs-Mineral Oil [40], MWCNTs-Silicon Oil [41], CuO-EG-distilled water [42], Ag-SiC-water [43], and hybrid nanofluids [44].

The thermo-physical properties of nanofluids are influenced by many factors, including, stability, temperature, nanoparticle volume fraction, nanoparticle shape and size, nanoparticle cluster and aggregation [45]. However, the commercialization of the nanofluids is influenced by the thermal conductivity enhancement by the accumulation of high thermally conductive nanoparticles such as comparatively large size of the colloidal particles, their clogging, abrasion, and sedimentation [46]. To address these issues, Choi [47] pioneered in the applications of nanofluids in 1995 used the nanofluids developed based on advanced synthesis methods for nano-metal particles exhibiting enhanced thermal conductivities. Since Lee et. al. [48] first time measured the thermal conductivity of nanofluids, different types of nanofluids have been investigated to investigate their thermal conductivity [49-52]. In our case we have used the Jatropha seed oil for the synthesis of the nanofluid because of its different advantages over conventional base fluids. These advantages include the easily availability of Jatropha seed oil in Malaysia, cost-effective than conventional base fluids, and environment-friendly as compared to the other conventional base fluids. Additionally, the Jatropha seed oil is found to be not suitable in food industry therefore, its utilization in heat transfer does not influence the food industry.

In the view of the above literature, following are the main objectives of this research:

- To synthesize the MWCNTs-Jatropha oil-based nano-dispersion via one-step method without addition of any surfactant.
- To investigate the thermal conductivity of the MWCNTs-Jatropha oil-based nanofluid over different nanoparticle volume fractions and temperatures.

2. Materials and Methods
Jatropha seeds were obtained from ACI Agro Solution, Jaipur, India. The Hexane (analytical grade) and Multiwalled Carbon Nanotubes (MWCNTs) were obtained from Merck (Malaysia).

2.1. Extraction of Jatropha Oil (JO)
Laboratory scale grinder was utilized to grind the Jatropha seeds and Jatropha seed oil was extracted in a Soxhlet extractor using n-hexane as a solvent at an elevated temperature of 68 °C over a period of 6 hrs. After that, a rotary evaporator was used to evaporate the n-hexane at a temperature of 70 °C for 1 hr. The resulted Jatropha oil was kept in airtight glass bottles for further experimental work.

2.2. Nanofluid Preparation and Characterization
Jatropha Seed Oil-based MWCNTs nanofluids were synthesized with dry MWCNTs (0.1wt./wt.) and pure Jatropha Seed Oil by using therefore called one-step method [46, 47]. This method is utilized to synthesize the nanofluids by using the MWCNTs volume fraction concentration of 0.2-0.8 wt.% at different
temperatures 25-65 °C. Mechanical mixing technique is imposed to disperse the MWCNTs. An ultrasonic probe-type disrupter with the (70%) amplitude and 2s ON/OFF pulse mode is used to stabilize all nanofluids samples. The ultrasonic probe-type disrupter gives a better dispersion of nanoparticles in the base fluid than bath-type ultrasonication. However, during the process, the temperature rises significantly due to disruption in agglomerates caused by the heat transfer through the ultrasonic waves. To address this issue, the nanofluids samples are ultra-sonicated with water bath cooling, Hashnin, HS 3005 N.

2.3. Thermal Conductivity Measurements
KD2 Pro KS-1 was utilized to measure the thermal conductivity of Jatropha oil and MWCNTs-Jatropha oil-based nanofluids at different temperature and nanoparticle concentrations. The instrument working principle is based on the transient hot-wire method with an accuracy of ±0.01 W/m.K and a maximum deviation of 5.0%. This technique has been widely used by academic researchers for experimental investigation of the thermal conductivity of nanofluids [27]. The temperature sensor inside the probe acquired the thermal conductivity based on temperature differences and measure the precise thermal conductivity by correcting the temperature drift. The probe is inserted into the nanofluids samples, which are prepared at different nanoparticle concentrations over different temperatures using a thermostatic bath.

3. Results and Discussions
The results of thermal conductivity are shown in (Figure 1). The thermal conductivity is found to be in the range of (0.178-0.221 W/m.K) over the temperature range of (25-65 °C) and MWCNTs concentration range of (0.2-0.8%). The thermal conductivity enhancement was found to be increased from 2.29% to 6.76% by increasing the temperature from 25 ° to 65 °C and the nanoparticle volume fraction from 0.2 wt.% to 0.8 wt.%.

Typical behavior of thermal conductivity enhancement with an increase in temperature as well as nanoparticle concentrations is an indication of higher thermal conductivity of MWCNTs as compared to Jatropha oil. The thermal conductivity enhancement and thermal conductivity ratios are calculated using Eq. (1) and (2) and results are shown in (Figure 2).

\[ K_{nf,Enhancement} = \left( \frac{K_{nf} - K_{bf}}{K_{bf}} \right) \times 100 \]  

(1)

\[ K_{nf,Ratio} = \left( \frac{K_{nf}}{K_{bf}} \right) \]  

(2)

The maximum thermal conductivity enhancement is found to be 1.067% at a higher temperature (65 °C) and a higher concentration of MWCNTs (0.8 wt.%). This phenomenon of thermal conductivity enhancement with an increase in temperature and MWCNTs concentrations can be attributed to the increase in Brownian motion. Brownian motion is improved by increase in the temperature and thermal conductivity enhancement also depends on the average particle size. The increase in the MWCNTs concentration in base fluid leads to increase in surface area to volume ratio for effective heat transfer through the collision of photons and electrons via conduction mode which is consistent with reported studies [48]. In addition, the increase in the MWCNTs concentration in base fluid leads to the decrease in distance between nanoparticles i.e. mean free path which causes the percolation effect i.e. enhancement in heat conduction [49]. This phenomenon may be attributed that decrease in mean free path causes an increase in the mass fraction which leads to the increase in lattice vibrational frequency and increases percolation mechanism of heat transfer. The effect of temperature on thermal conductivity enhancement can be attributed to the weakening of intermolecular and interparticle adhesion forces which cause an increase in Brownian motion and results from enhancement in thermal conductivity [50, 51]. The phenomenon of thermal conductivity enhancement can be reversed if agglomeration takes place among nanoparticles dispersed in the base fluid. The agglomeration can be prevented by incorporating the carboxylic functional groups on the surface of nanoparticles through acid treatment [30, 52].
Figure 1. Thermal conductivity of Jatropha oil and MWCNTs-Jatropha oil-based nanofluid at different temperatures and nanoparticle concentrations.

Figure 2. Thermal conductivity enhancement and thermal conductivity ratio of MWCNTs-Jatropha oil-based nanofluid at different temperatures and nanoparticle concentrations.

4. Conclusions
By considering the importance of the thermal and physical characteristics of the nanofluids for their applications in heat transfer, in this work, MWCNTs-Kapok seed oil-based nanofluid is prepared via a one-step method to investigate its thermo-physical properties over temperature (25-65°C) and ultrasonication time (1-6h). The results show that the viscosity decrease, and thermal conductivity increase with an increase in temperature of nanofluid. The maximum thermal conductivity enhancement of 6.76% is observed.

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