



PAPER

Thermal properties of ethylene glycol-carbon based nano-fluids

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Arti Bansal¹, Gyan Prakash Sharma¹, Ravi Agarwal²  and Ramvir Singh¹ ¹ Department of Physics, University of Rajasthan, Jaipur 302004, India² Centre for Converging Technologies, University of Rajasthan, Jaipur 302004, IndiaE-mail: rvs2020@gmail.com**Keywords:** thermal properties, nanofluids, carbon nanoparticles**Abstract**

We present results of thermal conductivity, thermal diffusivity, and specific heat of Ethylene Glycol (EG)-Carbon nano-fluids obtained using Thermal Constants Analyser (TPS 2200). A two-step method including a magnetic stirrer and an ultrasonic device was used to prepare stable EG-Carbon nano-fluids. Carbon nanoparticles were dispersed slowly in EG with different concentrations of 1 wt%, 2 wt%, 3 wt%, and 4 wt%. Thermal coefficients of the prepared nano-fluids at each concentration were measured at temperatures 10, 20, 30, 40, 50, and 60 °C. The percentage increment in thermal conductivity increases with concentration, as is evident from the observed increments of 20% and 31% for 1 wt% and 4 wt% concentration at 10 °C, respectively. The highest increase in thermal diffusivity of about 32% was observed when the loading of carbon nanoparticles was increased from 1 wt% to 4 wt% at 10 °C. On the other hand, the same increment in concentration at 10 °C led to a decrease of 15% in specific heat.

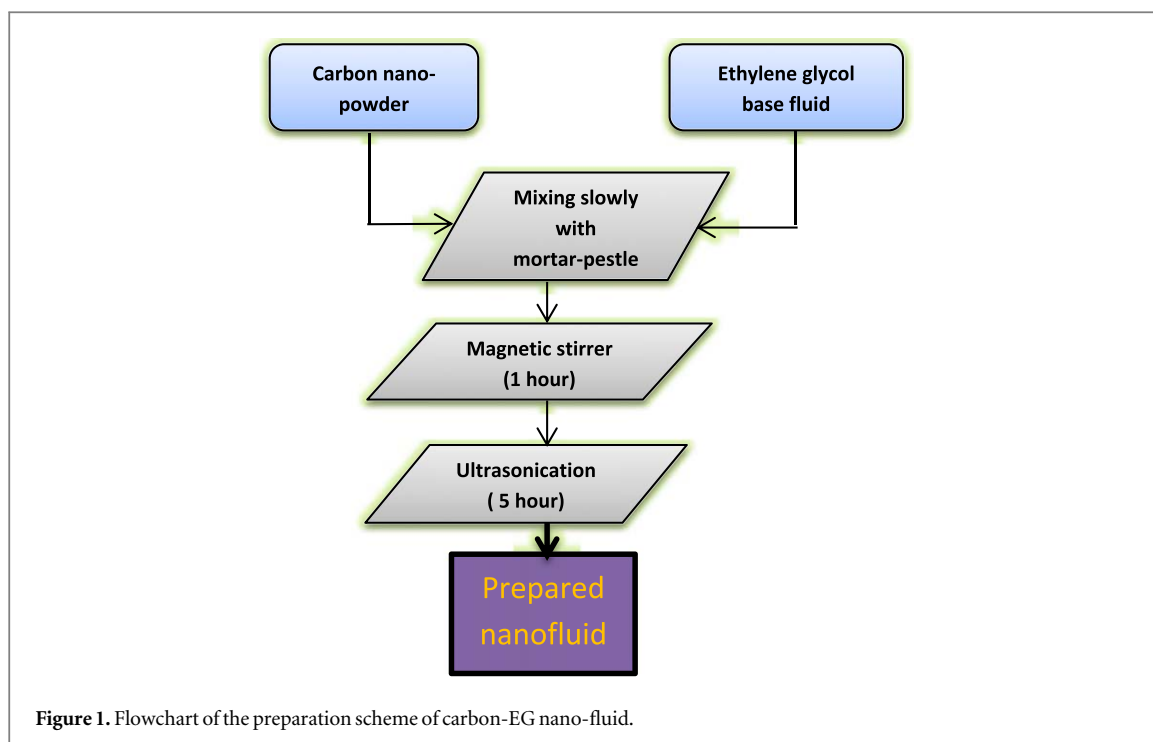
1. Introduction

Heat transfer through fluids is of vital interest to researchers in the field of thermal engineering, medical science, and processing industries. Water and oils are the conventional heat transfer fluids because of their low cost, high heat capacity, and abundant availability. To improve the thermal properties of these fluids, scientists have developed nanoparticle-based heat transfer fluids called nano-fluids [1–5]. Nano-fluids, as one of the newly emerged thermal fluids, have been intensively studied in many fields to advance their thermal engineering applications [6–14].

Because of the aforementioned utility of nano-fluids, many researchers have synthesized several different stable nano-fluids and have reported encouraging results. Dependence of the thermal conductivity of nanofluids on various parameters such as temperature, concentration, particle shape and size has been studied in various articles [15–17]. In particular, the analysis of neutron irradiation sensitivity of Al₂O₃ nano-fluids' thermal conductivity by Agarwal *et al* [18] is quite intriguing. When compared with the un-irradiated nano-fluids, the thermal conductivity of irradiated nano-fluids has been reported to decrease significantly depending upon the exposure time.

Nazari *et al* [19] presented a numerical study, the mixed flow of the non-Newtonian water-based Al₂O₃ nanofluid with 0%–4% nanoparticles volume fractions inside a two-dimensional square cavity with hot and cold lid-driven motion and porous media is simulated at Richardson numbers of 0.01, 10 and 100 and Darcy numbers of $10^{-4} \leq Da \leq 10^{-2}$ using Fortran computer code and results drawn for temperature domain, velocity, Nusselt number, and streamlines were discussed.

Some researchers have also studied thermal diffusivity [20] and specific heat [21] of nano-fluids. Murshed [22] measured the thermal conductivity, thermal diffusivity, and specific heat of nano-fluids simultaneously by using a transient double hot-wire technique. Upon analysis of several nano-fluids, it was demonstrated that, while the thermal conductivity and diffusivity of these nano-fluids increase with increasing volume fraction of nanoparticles, the specific heat, on the other hand, decreases. The increment in thermal diffusivity was slightly higher than that of thermal conductivity.



Recently, several studies [23–26] have been conducted on the use of carbon-based nanostructures to prepare nano-fluids. Most physical properties of carbon nanoparticles depend on the manufacturing technique used for them. Carbon nanoparticles have high melting and boiling points, high intrinsic thermal and electrical conductivity, low density (when compared with metals or metal oxide nano-particles), and high surface area. Because of these properties, there has been a great interest in the community to synthesize carbon nano-fluids. Several different carbon nanomaterials like carbon nanotubes [27–30], graphite nanoparticles [31], graphene nanoplatelets [32, 33], graphene oxide [34], nanofibers, and diamond nanoparticles [35] have been used to prepare nano-fluids for various applications.

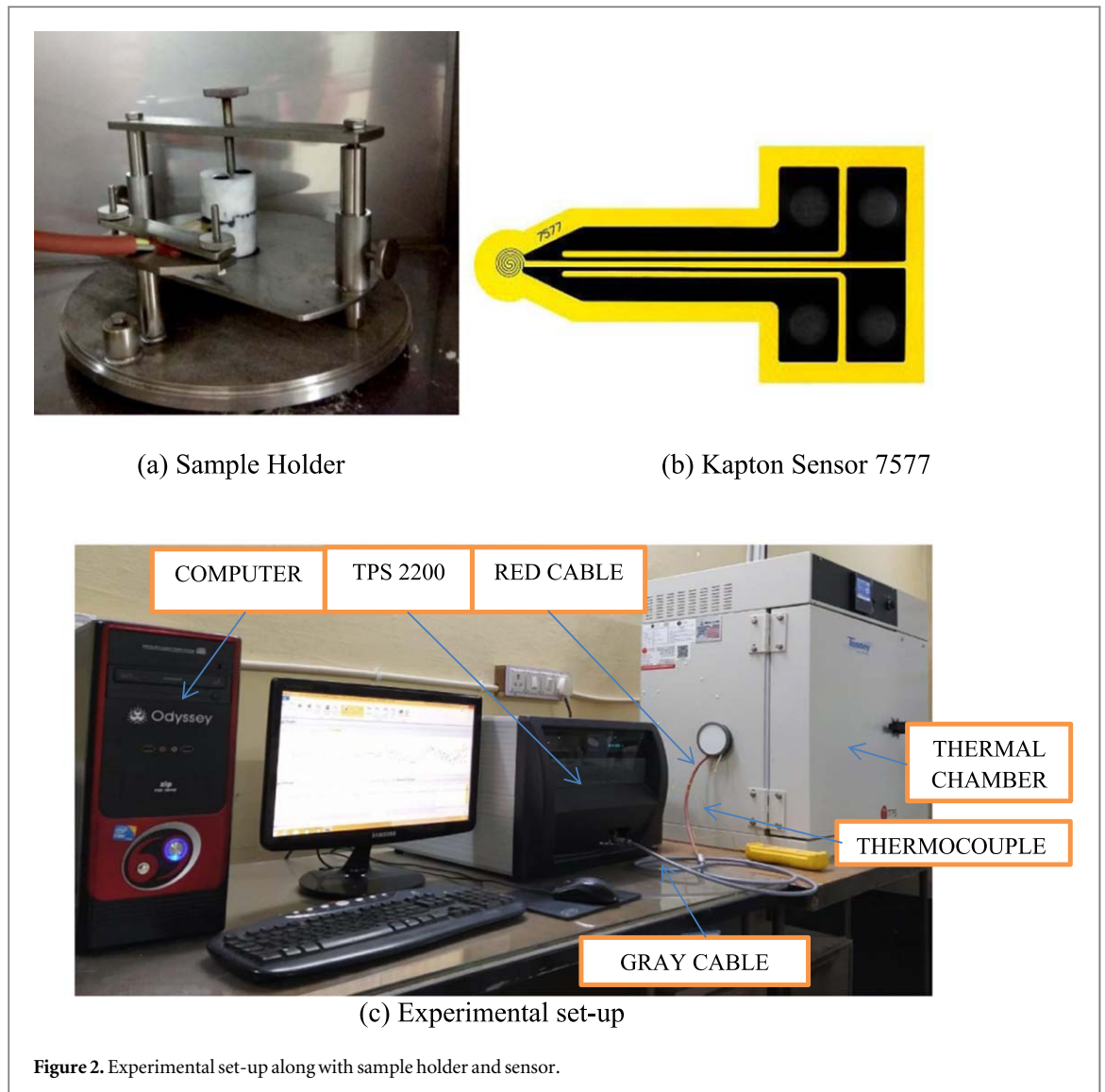
In this study, we use carbon nanoparticles of size less than 100 nm to prepare stable Carbon-Ethylene Glycol (EG) nano-fluids. Using the Transient Plane Heat Source (TPS) technique, we analyze the dependence of various thermal parameters of this nano-fluid on the temperature and weight concentration of carbon nanoparticles. At each concentration (1 wt%, 2 wt%, 3 wt% and 4 wt%) and temperature (10, 20, 30, 40, 50 and 60 °C), three different sets of measurements were recorded. At the same temperature, thermal conductivity and diffusivity of the nano-fluids were observed to increase with concentration. In contrast, the specific heat was observed to decrease.

2. Materials and method

2.1. Nano-fluid preparation

We used Carbon nano-powder (Sigma Aldrich) of size less than 100 nm and Ethylene glycol (Merck) throughout our investigations. A two-step method was employed to synthesize Carbon-EG nano-fluids. Using this method, we dispersed Carbon nano-powder into EG-base fluid very slowly to avoid agglomeration in the fluid. To produce homogenous nano-fluids, the following procedure was followed (see figure 1):

- Firstly, an appropriate amount of Carbon nano-powder (calculated according to the desired concentration) was measured with a weighing machine (Precisa; XB 220A) having 0.0001 gm precision.
- The measured amount of Carbon nano-powder was mixed slowly into EG base fluid using mortar and pestle (Cole-Parmer).
- The mixed fluid was stirred for one hour using a magnetic stirrer (Tarsons; SPINOT).
- After that fluid was sonicated for 5 h using an ultrasonic probe sonicator.



2.2. Measuring thermal properties of nanofluid

We measured the thermal conductivity, thermal diffusivity, and specific heat of the above-prepared carbon-EG nano-fluids at 1 wt%, 2 wt%, 3 wt%, and 4 wt% concentrations and 10, 20, 30, 40, 50, and 60 °C temperatures using Thermal Constants Analyser TPS 2200 (figure 2(c)). We used the 7577 Kapton sensor (figure 2(b)) to measure the thermal parameters for the pulse of 30 mW power for 10 s.

2.3. Standard deviation for thermal conductivity measurement

In order to eliminate sequential mechanical errors and temperature instabilities, we performed three measurements at each temperature within a span of 15 min. Standard deviation (SD) in the measurements of thermal conductivity of nanofluids [36] for different concentrations was obtained using the equation below,

$$SD = \sqrt{\frac{\sum_i [(TC)_i - \overline{(TC)}]^2}{n^2}}$$

where $(TC)_i$ is the thermal conductivity of Carbon-EG nano-fluid for each measurement, $\overline{(TC)}$ is the average thermal conductivity, and n is the number of measurements. The standard deviations for thermal diffusivity and specific heat were estimated in a similar fashion.

2.4. Experimental setup

For accurate measurement of thermal properties, sample temperature should be stable during the measurements. We used a dropper to fill the sample in the sample holder, ensuring that no air bubbles were present in the holder. The sensor was fixed in the sample holder, which was mounted on a stand (figure 2(a)). Both vertical and horizontal orientations of the sensor were implemented. Due to intense fluctuations in

measurement values in the vertical setting, we instead opted for the horizontal sensor setup, which provided relatively stable measurements. The whole setup was then placed in a high-quality thermal chamber (Tenney USA) for about two hours to attain the desired equilibrium temperature and to maintain its stability. A digital thermocouple was placed in the vicinity of the sample to measure the temperature of the chamber.

3. Results and discussion

The analysis by Xie *et al* [37] shows that the thermal properties of nanofluids could be influenced by a variety of factors including the volume fraction of the dispersed nanoparticles, the tested temperature, the thermal conductivity of the base fluid, the size of dispersed nanoparticles, the pre-treatment process and the additives of the fluids. We will now observe a manifestation of some of these factors in our study of the carbon-based EG nano-fluids.

Figures 3(a)–(e) shows the thermal conductivity of nano-fluid with varying temperature for different weight concentrations of carbon nanoparticles. The graphs clearly show that the thermal conductivity increases with increasing temperature. We can interpret this trend as follows. According to the conclusion drawn by Li Yu-Hua *et al* [38], the Brownian motion of particles, aggregation of nanoparticles, and viscosity are influenced by temperature. As the temperature increases, the surface energy of particles decreases which leads to a decrease in particle aggregation and fluid viscosity. This in turn intensifies the Brownian motion of particles, which ultimately leads to an increase in the heat transfer capability of nano-fluids. It can be concluded from figures 3(b)–(d) that while the thermal conductivity only moderately increases (by about 1%) in the first 10 °C of temperature change, the increment is rather significant when the temperature goes above 20 °C. The thermal conductivity increases by about 7% when the temperature is changed from 20 to 60 °C for all concentrations except for 3 wt%, for which the increase is about 5%.

Figure 3(f) shows the variation in thermal conductivity as a function of loading of Carbon nanoparticles in ethylene glycol base fluid up to 4 wt%. The figure shows enhancement in thermal conductivity with an increase in the concentration of carbon nanoparticles. A high concentration gives a large surface area for nanoparticles to transfer heat which leads to an increase in thermal conductivity.

Figure 4 depicts the percentage increment in thermal conductivity of Carbon-EG nano-fluid when compared to the EG base fluid as a function of loading at different temperatures ranging from 10 to 60 °C. Substantial percentage enhancement in thermal conductivity is seen for the carbon-EG nano-fluid. The thermal conductivity enhancement ratio for weight concentrations 1 wt% and 2 wt% are almost identical, which lie approximately around the 20% mark. When the loading is 3 wt%, the thermal conductivity enhancement ratio is 27% at 10 °C and further decreases as temperature increases. The highest increment, in this case, is 31% at 10 °C at 4 wt% loadings of carbon nanoparticles. The data clearly portrays that the percentage enhancement in thermal conductivity decreases as the temperature increases at a fixed loading of carbon nano-particles nanoparticles at different temperatures.

Figure 5(a) depicts the change in thermal diffusivity with temperature ranging from 10 °C to 60 °C at different concentrations of Carbon nanoparticles from 1 wt% to 4 wt%. In contrast with thermal conductivity, which indicates the quantity of heat energy that can be transferred through the given material, thermal diffusivity is a measure of the speed with which the transfer happens.

The variation in thermal diffusivity with a change in weight concentration and temperature is presented in figures 5(a) and (b). Ali *et al* [39] demonstrated that both the thermal conductivity and thermal diffusivity of Al₂O₃ nano-fluids increase as the concentration increases. This enhancement can be attributed to many factors such as ballistic energy, nature of heat transport in nanoparticles, and interfacial layer between solids/fluids. Heat transfer in fluid occurs at the particle-liquid interface. If the interfacial area is large, then more amount of heat energy will be transferred. At higher concentrations, nanoparticles become more clustered and the particle-liquid interfacial area also increases, both of which lead to an increase in the thermal conductivity and diffusivity of the nano-fluid. We observe similar trends in figure 5(b), where it is evident that the thermal diffusivity is enhanced as the weight concentration of Carbon nanoparticles increases. The thermal diffusivity enhancement ratio at 10 °C between 4 wt% and 1 wt% loading is approximately 32% and further decreases as temperature increases. A quick glance at figure 3(f) suffices to conclude that the enhancement ratio of thermal conductivity is lower than that of thermal diffusivity. In addition, a significant increase of about 5%–6% in thermal diffusivity (at each concentration of 1–3 wt%) is observed when the temperature increases from 10 to 60 °C. When the concentration is increased to 4 wt%, enhancement in thermal diffusivity is about 12% in the same temperature range.

Figure 6(a) exhibits the variation in the specific heat of Carbon-based nano-fluids with changing the temperature at 1 wt%, 2 wt%, 3 wt%, and 4 wt% concentration of Carbon nanoparticles. The results show a linear enhancement in the specific heat as temperature increases from 10 °C to 60 °C. However, figure 6(b)

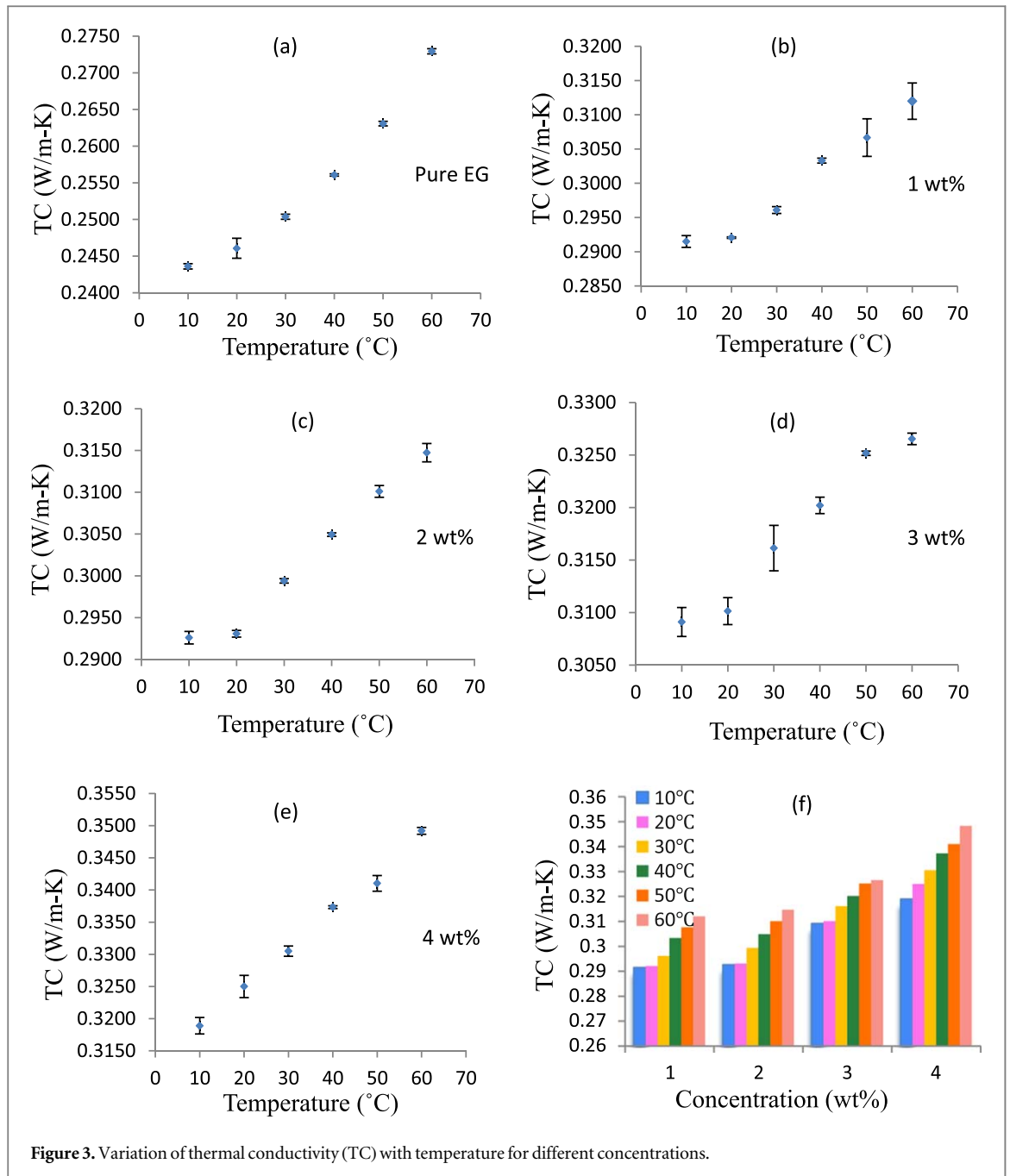


Figure 3. Variation of thermal conductivity (TC) with temperature for different concentrations.

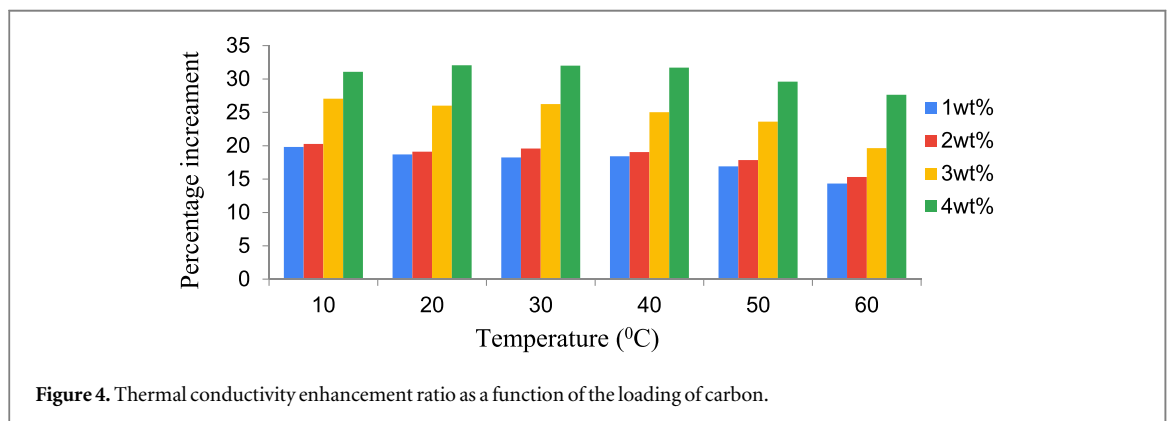


Figure 4. Thermal conductivity enhancement ratio as a function of the loading of carbon.

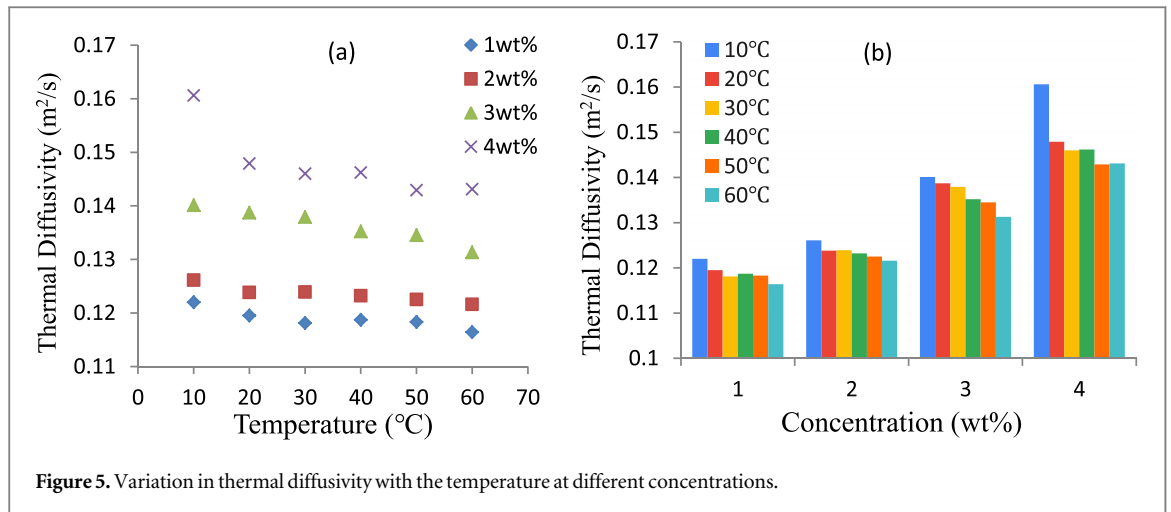


Figure 5. Variation in thermal diffusivity with the temperature at different concentrations.

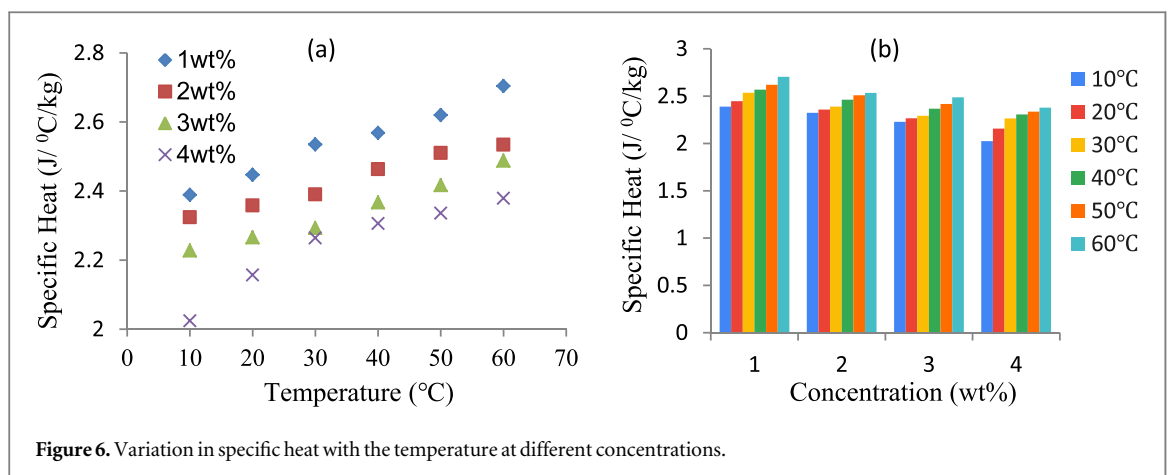


Figure 6. Variation in specific heat with the temperature at different concentrations.

shows that the specific heat decreases with an increase in nanoparticle loading. The specific heat decrement ratio for 1 wt% to 4 wt% is approximately 15% at 10 $^{\circ}\text{C}$. Specific heat is a measure of the substance's heat storage capacity. So for higher clustering of nanoparticles, the heat stored by the nano-fluid is decreased.

Similar trends have been observed in other studies, such as that of Yiamsawasd *et al* [40], where the specific heat of TiO_2 and Al_2O_3 nano-fluids in base pure water and a mixture of ethylene glycol/water (20/80 wt%) was scrutinized.

4. Conclusions

In this study, we prepared carbon EG-based nano-fluids using a two-step approach. The thermal conductivity, thermal diffusivity, and specific heat of prepared nano-fluids were measured by a thermal constants analyzer (TPS-2200) at different temperatures and concentrations. When compared with the EG-base fluid, the thermal conductivity of the carbon-based EG nano-fluid was found to be about 32% higher at 20 $^{\circ}\text{C}$ at 4 wt%.

Our analysis shows that as the weight fraction of carbon nanoparticles in the fluid increases at a fixed temperature, the thermal conductivity and diffusivity also increase whereas the specific heat decreases. More explicitly, our results show that thermal conductivity and thermal diffusivity increase by approximately 9.4% and 31.6%, respectively, as the nano-particle loading increases from 1 wt% to 4 wt% at 10 $^{\circ}\text{C}$. On the other hand, the same variation in concentration at the same temperature leads to a decrease in the specific heat of about 15.3%. An increment in thermal diffusivity is clearly higher than that in thermal conductivity.

The varying temperature at a fixed concentration showed that while the thermal conductivity and specific heat increase with increasing temperature, the thermal diffusivity decreases. At a fixed concentration of 4 wt%, thermal conductivity and specific heat of the nano-fluids showed a 9.2% and 17.5% increase as the temperature was increased from 10 to 60 $^{\circ}\text{C}$. In contrast, the same temperature change led to a decrease of 10.9% in thermal diffusivity at the same concentration.

Our measurements were performed over a 24 h period, at intervals of 6 h each. Each of these 4 sets of measurements displays almost similar results, thus showing that the nano-fluid remains stable over this time interval. The next set of readings, taken on the second day, started deviating from the previous data values. This observation can be attributed to the fact that the nano-particles in the fluid begin to settle down after about a day, thus affecting the fluid stability.

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