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Research Article

Experimental investigation on thermal conductivity and stability of water-graphite nanofluid

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ABSTRACT

Enhanced thermal conductivity of nanofluids has proven importance in enhancing heat transfer for many application. In this study, thermal conductivity of graphite nanopowder dispersed in water at different temperatures was studied experimentally. Stable nanofluids of different concentrations (0.2 vol%, 0.5 vol%, 0.8 vol%, 1 vol% and 1.5 vol%) are prepared using ultrasonic cleaner by sonicating for 3 hour. Thermal conductivity was measured from temperature 25 to 55 °C with an interval of 5 °C using KD2 Pro thermal properties analyser. Experimental results showed that thermal conductivity increases with increase in temperature and volume concentration. Thermal conductivity of Water – Graphite nanofluid showed enhancement of 5.6% to 20.42% for 0.2 vol% to 1.5 vol% of concentration at 25 °C respectively. However, the maximum improvement of 39.72% was found at 1.5% of concentration at 55 °C compared to water. A correlation was developed considering the effect of temperature and concentration using the regression method. The proposed correlation effectively predicts the thermal conductivity of Water – Graphite nanofluids with an accuracy of ±2.8%.

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INTRODUCTION

Nanotechnology plays a crucial role in material science, electronics, biomedical and biomaterials etc. This technology is used to produce nanoparticles of different materials containing a particle size of less than 100 nm. These particles are used to disperse in base fluids such as water, Ethylene glycol (EG), propylene glycol (PEG) and oil etc., which are termed as nanofluids. These solid and liquid mixtures of different nanoparticles are capable of providing better thermal properties than that of base fluids. Nanofluids are used in a different application such as heat transfer medium, tribological nanofluids, surface coating, chemical processing, environmental, biomedical and pharmaceutics [1]. Several experimental studies related to thermal conductivity (TC) [2–5], convective heat transfer (CHT) [6–8], and heat absorption rate [9] were reported with possibilities to use nanofluids in heat transfer applications. Heat transfer studies using numerical techniques have proved the possibilities

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of improving the heat transfer [10–13].Thermal conductivity is one of the property of a nanofluid which is essential for the evaluation of heat transfer coefficient under different flow condition and operating temperature. This property of fluid changes with the volume concentration, size of the nanoparticles and temperature of the nanofluid [14]. Industrial system utilizes extensively water as fluid for heat transfer for cooling and heating purpose. Hence, enhancing its property by preparing water based nanofluids have attracted various researchers, so that the performance of industrial systems can be improved. These fluids are presumed to improve the heat transfer capabilities due to their enhanced thermal conductivity.

Putra et al., [15] explored thermal conductivity enhancement with an increase in temperature for Al_2O_3 and CuO nanofluids. Their study resulted with a 2 to 4 time increase in TC enhancement over a temperature range of 21°C to 51°C as compared to the base fluid at identical temperature. Tavman et al., [16] presented an experimental study on TC using water as base fluid and alumina and silica as nanoparticles at different volume concentration (0.5% to 4%) using a 3ω method. Their result showed significant improvement in TC at a measured range of temperature. Murshed et al., [17] carried out the experimental studies on TC of water based TiO_2 nanofluid and reported 30% of enhancement for the spherical shaped nanoparticles. Chandrashekar et al., [18] studied the effect on TC by varying concentration (0.33–5%) of Al_2O_3 nanoparticles (43 nm) in water and reported significant enhancement. Patel et al., [19] used different nanoparticle materials and particle sizes at a various concentration to study the effect of temperature (20–50 °C) on TC. The result showed that enhancement of TC depend upon the conductivity of material and particle size. Sundar et al., [20] studied the effect of Fe_3O_4 nanoparticles concentration in water on thermal conductivity at different temperature. The study indicated noticeable improvement in TC compared to the base fluid at all temperature and concentration. Similar study was conducted by Agarwal et al., [21] to present CuO nanoparticles in water having concentration up to 2%. Their study reveals that thermal conductivity strongly affected due to a change in concentration and temperature. Srinivas and Vinod [22] performed TC study considering water as a base fluid with adding Al_2O_3, CuO and TiO_2 nanoparticles. They reported significant improvement in TC as compared with base fluid at identical temperatures.

Many researchers have conducted thermal conductivity of nanofluids using THWM (transient hot wire method) to study the effect of temperature and concentration. Some of the selected literatures are presented in the Table 1. Zhu et al., [23] used graphite nanoparticles of 15 nm size to measure thermal conductivity by preparing water based graphite nanofluids up to 2% of concentration. They reported 34% of enhancement for 2% concentration at room temperature. Ladjevard et al., [24] performed the solar radiation absorption measurement using graphite nanofluid utilizing solar collector. They discovered that by adding graphite nanoparticles, incident irradiation and incident irradiation energy can be absorbed up to 50% and 27% respectively. Accordingly, Hussein et al., [25] reported comprehensive overview and understanding about the recent advances related with the application of the different kind of nanofluids in the direct absorption solar collectors. Hajjar et al., [26] synthesized graphite oxide nanosheets and dispersed homogeneously in the water. They performed thermal conductivity test at different temperature by varying weight concentration from 0.05 to 0.25 wt%. Results showed an enhancement of 33.9% at 20 °C and 47.5% at 40 °C for 0.25 wt% of concentration respectively. Wang et al., [27] dispersed graphite nanoparticles into the oil using mechanical ball milling and performed thermal conductivity measurement at different concentration. Their study resulted in maximum enhancement of 36% at 1.36% of concentration. Substantial improvement in convective heat transfer was reported using graphite – SiO_2 and water (hybrid) nanofluid compared to water[28]. Experimental investigation on thermal conductivity measurement of carbon nanotubes – water based nanofluids showed significant improvement in TC [29].

From the literature, it is observed that water based nanofluids have shown improved thermal conductivity. However, nanofluids containing graphite nanoparticles

Table 1. Review of some selected literature for water based nanofluids

Author	Particle/ Size	Volume Concentration	Method	Temperature	Enhancement (%)
Manna et al., [30]	SiC/27 nm	0–8%	KD2 Pro	Room temperature	26%
Sundar et al., [20]	Fe_3O_4/13 nm	0–2%	THWM	20–60 °C	48%
Agarwal et al., [21]	CuO/54 nm	0–2%\	KD2 Pro	10–70 °C	40%
Sundar et al., [31]	Nano Diamond/15 nm	0.2–1%	THWM	20–60 °C	22.86%
Maheshwary et al., [32]	TiO_2/35 nm	0.5–2.5%	THWM	30–80 °C	69.43%
Huminic et al., [33]	SiC/25 nm	0.5–1%	KD2 Pro	20–50 °C	17.62%
Kolappan et al., [34]	ZrO_2	0.1-.3%	KD2 Pro	Room temperature	9.22%
Ranjbarzadeh et al., [35]	Silica/50 nm	0.1–3%	KD2 Pro	25–55 °C	38%

were reported very few even though graphite nanoparticles possess very good thermophysical properties such as high thermal conductivity and low density. Moreover, the graphite based nanofluids can able to provide better stability due to its lower density. Hence, in this study, water based graphite nanofluid (Water – Graphite) is considered to examine the thermal conductivity by varying the volume concentration. For this, volume concentration of 0.2 to 1.5 vol% was considered and prepared. Subsequently, thermal conductivity of prepared nanofluids was measured for the temperature range of 25 °C to 55 °C. Finally, a correlation was developed using the present experimental results.

MATERIAL AND METHOD

Nanofluid Preparation

Preparation of nanofluids plays a vital role to accomplish good stability for a longer time. Subsequently, the stable dispersion of particles in water can provide uniform thermal conductivity at respective nanofluid concentration. Researchers have prepared stable nanofluids using Two methods, Single step (S – S) method and two step (T – S) method. In S – S method both nanoparticle synthesis and nanofluids are obtained in the combined form at a time [36]. In T – S method, particles are produced in the dry form initially, then nanofluid dispersions are formed using stirring and ultrasonication. Nanoparticles of different sizes have been produced using several methods[37,38]. However, T – S method was widely adopted by the researchers in the preparation of many types of nanofluids [20,35,39–41] due to ease in preparation of predetermined concentration. Graphite nanopowder (Sisco Research Lab (SRL), Maharashtra) with particle size <50 nm was procured to prepare Water – Graphite nanofluids. Density of graphite nanoparticles are 2250 kg/m^3. The Field Emission Scanning Electron Microscopy (FESEM, Carl Zeiss Gemini Column, EHT: 3KV to 25KV, resolution 200μm to 20nm) was used to take image of graphite nanoparticles and shown in Fig. 1. It can be seen that hat average particles size is very close to 50 nm size.

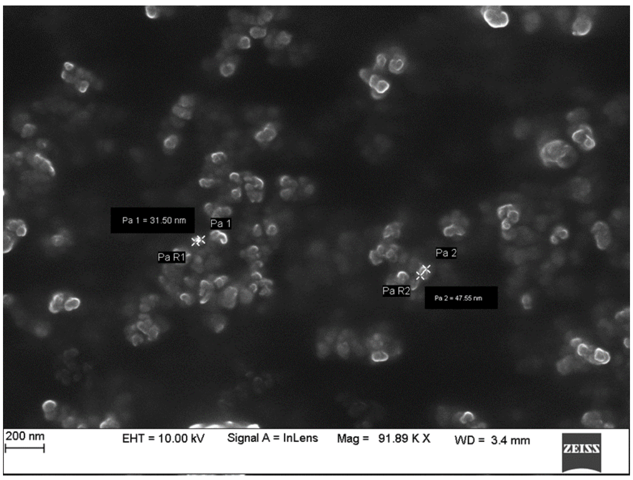

Figure 1. FESEM image of graphite nanopowder obtained from SRL.

Initially, water of 50 ml was taken in a beaker, then added with PVP K-30 (Polyvinylpyrrolidone) of 0.1 wt% and the solution was stirred with a magnetic stirrer for 1 hour. Afterwards, graphite nanoparticles required for 0.2 vol% of concentration was measured in an electronic balance with an accuracy of 0.001 g. The amount of nanopowder required for concentration was calculated by using the Eq. (1)

$$\varnothing = \frac{\frac{m_g}{\rho_g}}{\frac{m_g}{\rho_g} + \frac{m_w}{\rho_w}} \quad (1)$$

Where m_g, ρ_g, m_w, and ρ_w weight of graphite nanoparticles, the density of graphite nanoparticles, the weight of water and density of water respectively. The measured graphite nanoparticles were added to the previously prepared dispersion solution in a conical flask and stirred for 30 minutes in a magnetic stirring (REMI 2MLH) at 700 rpm. Furthermore, this mixture has undergone to sonication process in ultrasonic cleaner (Sidilu C – B, 40kHz, Sidilu ultrasonics, Bengaluru) for 3 hour to ensure a stable, uniform and continuous suspension. During the sonication process, the temperature was increased to 40 °C to 50 *°C* due to continuous sonication. To avoid continuous heating of a sample every 30 min fresh cold water (10 °C) was replaced. Subsequently, the aforementioned procedure was followed to prepare the 0.5%, 0.8%, 1% and 1.5% of concentration.

Evaluation of Stability

In this study, nanofluid of 0.1% of concentration was prepared at different ultrasonication time (30, 60, 120, 180 and 240 minutes) separately. Then each sample was tested for the zeta potential using Horiba SZ-100-Z and zeta potential values were obtained.

Thermal Conductivity

Thermal conductivity of Water – Graphite nanofluids is measured using a KD2 Pro thermal properties analyzer (Decagon Devices, Inc., USA). This instrument works on the principle of the transient hot wire method (THWM). KD2 Pro is one of the simple and accurate method to measure thermal conductivity and has been used broadly by many researchers [39,41–44]. This instrument consists of a battery, microcontroller and a sensor needle. The battery is the main power source for the analyzer, sensor needle acts as a heating medium and thermistor. A microcontroller is used to interpret the data and store in flash memory. The thermal conductivity estimation is done by assuming a few effects like infinite heat source, isentropic and homogeneous medium and with a uniform temperature. The sensor needle considered in the present study is KS-1 as suitable for the measurement for low viscous and lower thermal conductivity of liquids [45]. This needle consists of stainless steel with a 60 mm length and 1.3 mm of diameter. The KS-1 sensor needle can able to measure the thermal conductivity of liquids in the range of 0.2 to 2 W/m K with an accuracy of ±5% [45]. The time taken to measure the thermal conductivity is 60 s, first 30 second takes to stabilize the temperature of sensor needle with stabilizing the sample temperature and then by heating and cooling of sample for a 30 s each.

Determination of thermal conductivity starts with introducing the sensor needle into the sample (nanofluid) by taking adequate care during placing the needle into the sample to avoid bending of the sensor as shown in Fig. 2. TC Measurement of particular concentration was taken considering five readings at each temperature allowing 15 minutes of interval time between each reading. Average of these reading was used for reporting in results. To measure thermal conductivity at different temperature sample was carefully placed inside the constant temperature bath by maintaining temperature constant from 30 °C to 55 °C (Fig. 2). However, the room temperature was maintained at 25 °C. Before measuring the TC of Water – Graphite nanofluid TC of water was measured at identical temperate and compared with the data from literatures. Fig. 3 shows the comparison of TC of water at a different temperature from standard data [46] with KD2 Pro measurement. Uncertainty was carried out using the standard method from Moffat et al., [47]. Uncertainty in thermal conductivity is within ±0.95%

RESULTS AND DISCUSSION

Stability

Stability of nanofluids is one of the influencing parameter to use nanofluids for any applications. Stability of Water – Graphite nanofluid depends on the various factors such as ultrasonication duration, additives, pH, etc. [48]. Proper ultrasonication time can increase the stability of dispersion for a longer time [49]. To optimize the dispersion stability, the ultrasonication time was varied from 30–240 min. Subsequently, the zeta potential test was performed at different ultrasonication time. Zeta potential is the potential difference existing between the surface of solid particles immersed in a liquid and the bulk of the liquid. Based on the range of zeta potential values dispersion stability can be decided.

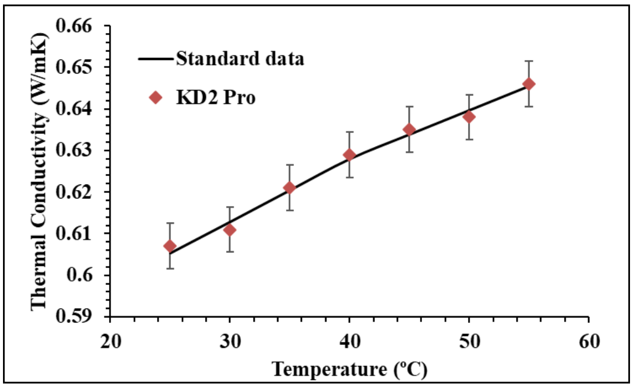

Figure 3. Thermal conductivity of water compared with KD2 Pro result and standard data [46].

Table 2 shows the zeta potential values for the different ultrasonication time. It can be observed from Table 2 that sonication time strongly effect on the zeta potential value of the nanofluid. For lower sonication time i.e, 30 and 60 min, zeta potential value obtained was –5.1 mV and –14.1 mV respectively. This shows that particles tend to form aggregation and sedimentation occurs. However, at higher ultrasonication time i.e more then 1 hour, Water – Graphite nanofluids exhibited very good zeta potential values, which confirms the stable dispersion of graphite nanoparticles in water. The zeta potential values obtained are -34.3 mV, -66.2 mV and -41.9 mV for the 120, 180 and 240 min of sonication as shown in Fig. 4(a), 4(b) and 4(c) respectively. It is also observed that zeta potential value for 240 min of sonication was less compared to the 120 and 180 min. Thus, it shows that prolonged ultrasonication can also reduce the stability of nanofluid due to improper dispersion. Hence, the optimized ultrasonication duration of 180 min (3 hour)

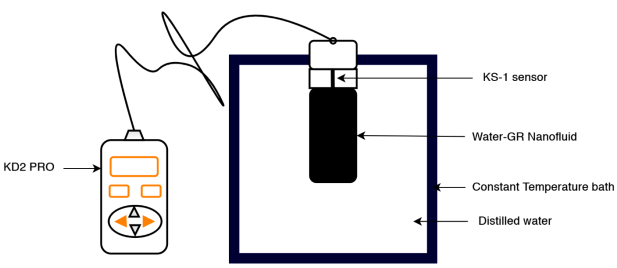

Figure 2. Experimental arrangement for thermal conductivity measurement of Water – Graphite nanofluid.

Table 2. Zeta potential values for the 0.1 vol% of Water – Graphite nanofluids at different sonication

Sonication Time (Min)	Zeta Potential (mV)	Stability
30	–5.1	Strong agglomeration
60	–14.5	Incipient instability
120	–34.3	Moderate stability
180	–66.2	Very good stability
240	–-41.9	Good stability

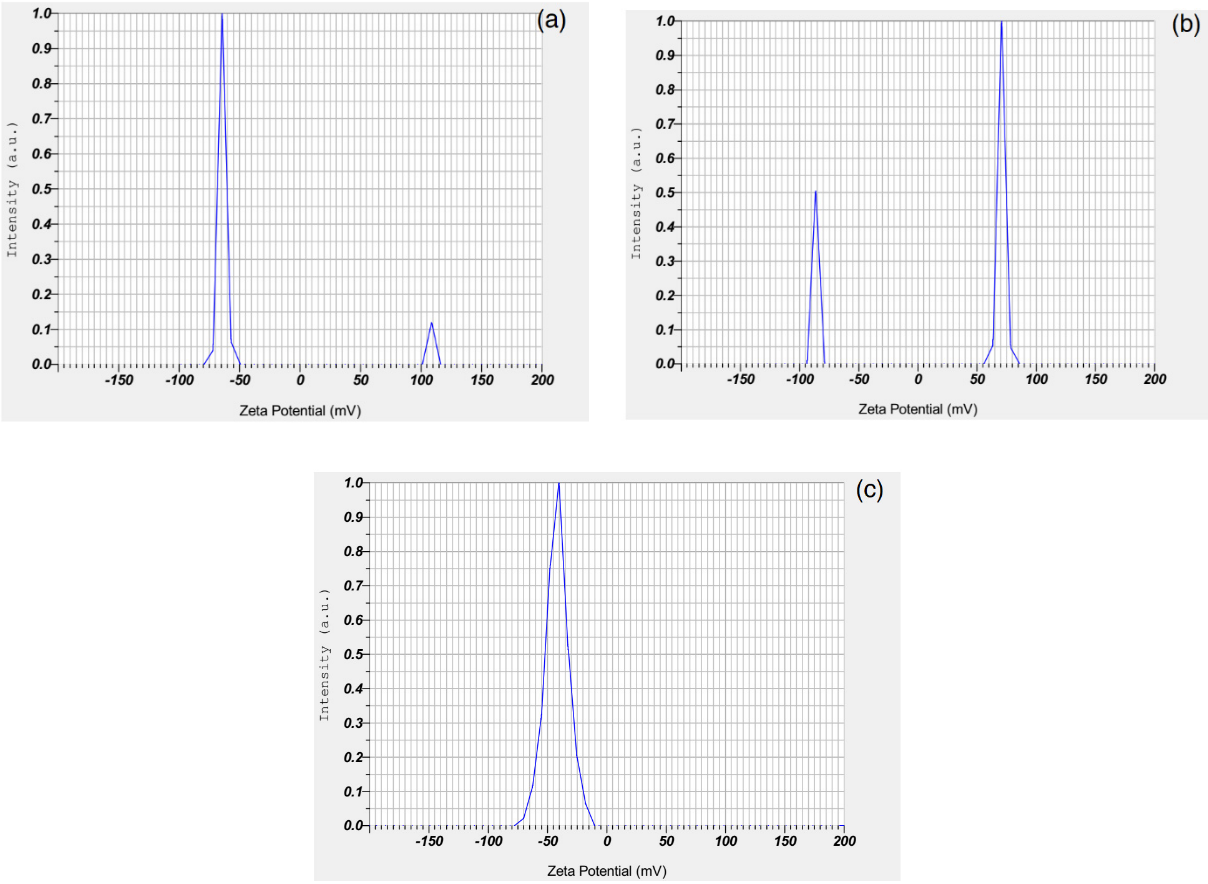

Figure 4. (a) Zeta potential at 120 min of sonication (b) Zeta potential at 180 min of sonication (c) Zeta potential at 240 min of sonication.

was employed to prepare the nanofluid for the present study.

Thermal Conductivity

In this section, the experimental results obtained for TC of Water – Graphite nanofluids are presented for the volume concentration of 0.2 to 1.5% in the temperature range of 25 °C to 55 °C. The effective thermal conductivity (ETC) of Water – Graphite nanofluid is defined as $k_e = \frac{k_{nf}}{k_w}$. The effect of temperature on thermal conductivity of Water – Graphite nanofluid is shown in Fig. 4(a). It can be observed that TC of the nanofluid increases with increase in temperature. This can be attributed two possible reasons: (1) when the distribution of the particles is modifying the water property as a solid and liquid mixture, in turn, to cause increase in the thermal conductivity. (2) increase in Brownian motion of particles due to the increase in temperature. Fig. 5(a) illustrates the effect of thermal conductivity trend and can be observed that thermal conductivity of Water – Graphite nanofluid increases from 0.641 to 0.740 W/m K for 0.2% to 1.5 % volume concentration due to the effect of volume concentration at room temperature. Fig.5 (b) illustrates the effect on ETC variation due to change in temperature with nanoparticles concentration in water. It can be observed that at a lower concentration of graphite particles thermal conductivity is less compared to higher concentration, this is due to the amount of graphite nanoparticles present in the water is less and provides less enhancement of thermal conductivity compared to water. However, at higher concentration number of particles collision and amount of energy transferred between the layers of the fluid considerably more, as a result of this thermal conductivity slop increases. As the graphite particles increases in the concentration, solid particles with higher TC added to the base fluid, due to this TC increases. This dependency is predominate because of the nanoparticle nature and their greater thermal conductivity, which effects on the base fluid to alter the property such as improved thermal conductivity and this effect depends on the number of nanoparticles steadily preserved by the water.

Thermal conductivity of nanofluids at different concentration are presented in Fig. 6(a) represents the thermal conductivity effect under the variable volume concentration at an individual fixed temperature. The variation can

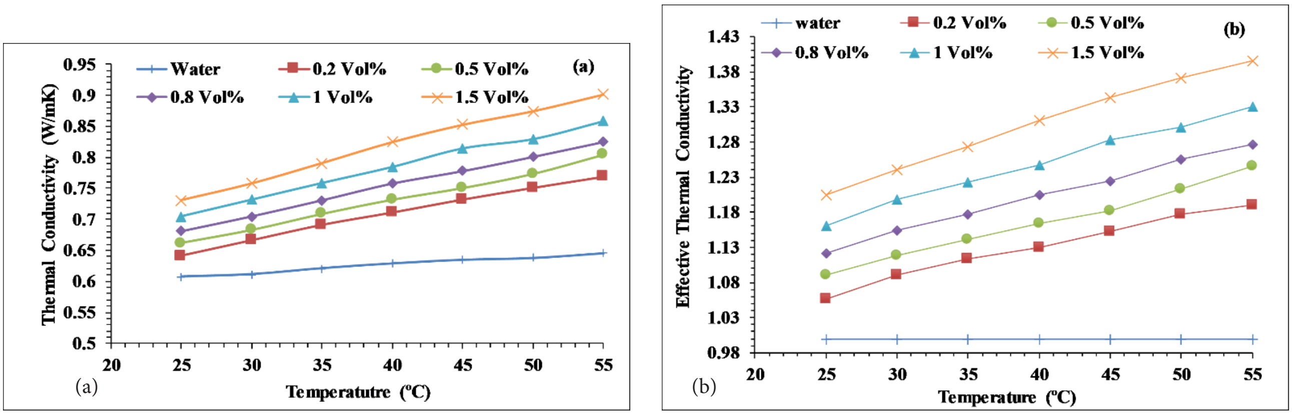

Figure 5. (a) Thermal conductivity of Water – Graphite nanofluids at different temperature (b) Effective thermal conductivity of Water – Graphite nanofluids at different temperature.

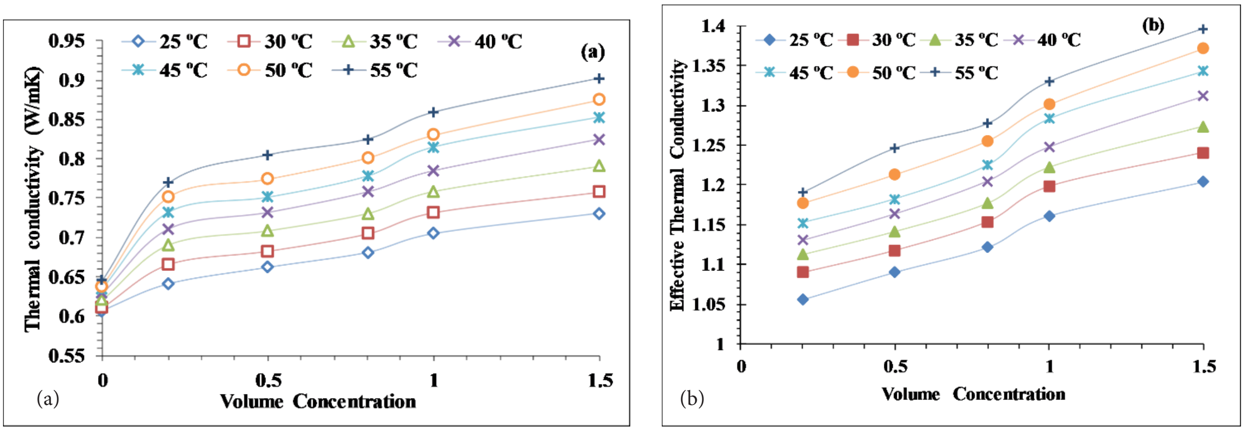

Figure 6. (a) Thermal conductivity of Water – Graphite nanofluids at different concentration of graphite nanoparticles (b) Effective thermal conductivity of Water – Graphite nanofluids at different concentration of graphite nanoparticles.

be attributed to the effect of nanoparticles motion within the water and layers of nanofluid. This enhances the particles to particles collision due to the random motion of particles. Subsequently, thermal conductivity of nanofluids increases with corresponding increase in temperature. It can be seen from Fig. 6(b) that enhancement at lower concentration (0.2%) is 5.6% at 25 °C. However, for a higher concentration (1.5%) at the same temperature is 19.04%, which is higher compared to the lower concentration. Therefore, approximately 13% of enhancement of TC compared to the base fluid at an identical temperature from 0.2 to 1.5%. Similarly, at higher temperature (55 °C) increase of thermal conductivity is 19.2% compared to the lower concentration. This is can be related to the molecular motions, which triggered rapidly to a greater extent as the temperature increases to a higher temperature. Table 3 represents the percentage of enhancement of TC for Water – Graphite nanofluids at the experimental condition in a temperature range of 25 °C to 55 °C. It can be seen from the experiment that the TC of nanofluid increases by increasing the concentration as well as the temperature. Subsequently, too

Table 3. Enhancement in thermal conductivity of Water – Graphite nanofluids at a measured temperature range (25–55 °C)

Concentration	Enhancement in TC (%)
0.2	5.6–19.40
0.5	9.06–24.61
0.8	12.19–27.70
1	16.14–32.97
1.5	20.42–39.62

much increase in the concentration could cause complications of unsteadiness of nanoparticles in the water or a drastic increase of viscosity and increases required pumping power. However, some thermal application the essential requirement is to obtain maximum improvement in heat transfer rather than the increase in pumping power. Hence, in such a situation the use of nanofluids can be more effective even using the higher concentration of nanofluid. The present study encourages possibilities of using Water

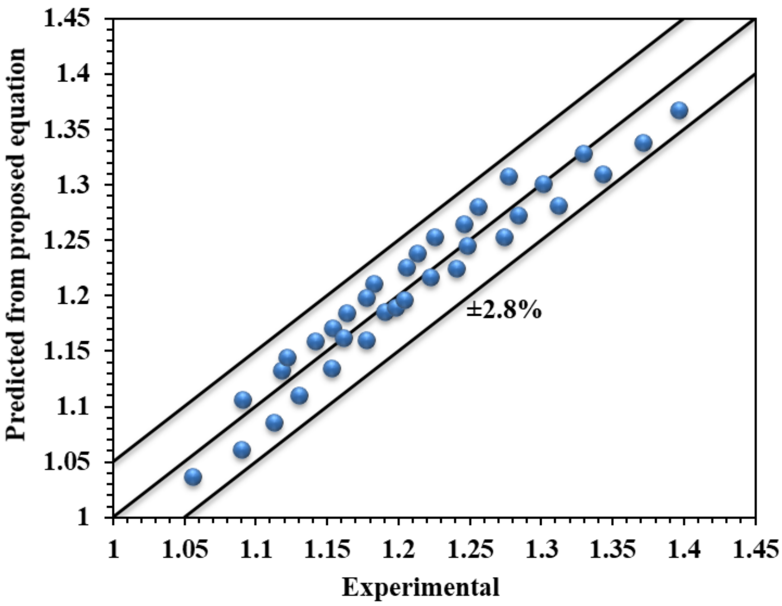

Figure 7. Comparison of predicted effective thermal conductivity from the proposed equation with experimental.

– Graphite nanofluid in applications such as heat exchangers, solar absorption, solar water heaters, cooling systems for automobile, and ventilation systems owing to longer stability and promising thermal properties over pure water.

In this study, correlation was developed to predict the effective thermal conductivity using the regression method in excel. The proposed correlation as a function of volume concentration and temperature as follows.

$$k_e = 1.028\ \varnothing^{0.071} \left(\frac{T_{Gnf}}{T_o} \right)^{1.394} \tag{3}$$

Where k_e is effective thermal conductivity, $\varnothing$ is volume concentration and T_{Gnf} is the temperature of Water – Graphite nanofluid. T_o *(273 K)* is reference temperature. R^2 value obtained was 0.93. This correlation was compared with the experimental data as shown in Fig. 7. It can be observed that the predicted and experimental data are very close to equity line which shows the good agreement of the proposed equation with the experimental results. The maximum and minimum deviation was within ±2.8%.

CONCLUSION

In this study, different concentration of Water – Graphite nanofluids is prepared using an ultrasonic cleaner with selecting the optimum sonication time. Thermal conductivity was measured at a different temperature from 25 °C to 55 °C using KD2 Pro thermal properties analyser by placing the samples at a constant temperature bath. Experimental results have shown significant improvement in thermal conductivity of Water – Graphite nanofluids due to the addition of nanoparticles into the base fluid. Thermal conductivity increased with an increase in temperature at all concentration compared to the base fluid. The increase in thermal conductivity was found to be 5.6% to 19.40% at 0.2% of volume concentration for temperature 25 °C to 55 °C. However, at same temperature range, 1.5% volume concentration exhibits enhancement of 20.42% to 39.62% compared with the base fluid. The correlation was developed taking temperature and concentration as a variable using the regression method. The proposed correlation effectively predicts the thermal conductivity of Water – Graphite nanofluids with an accuracy of ±2.8%.

NOMENCLATURE

k	Thermal conductivity, W/m K
T	Temperature, °C

Greek symbols

$\varnothing$	Volume concentration

Subscripts

g	Graphite nanoparticles
w	Water
nf	Nanofluid
e	Effective

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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