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Enhancing Heat Exchange Efficiency with Graphene and Titanium Carbide Nanofluids: Investigating Viscosity Influences on Thermal Systems

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Abstract

Researchers have been looking at heat exchange systems as of late to determine which is the most dependable and effective. In comparison to traditional heat transfer fluids, the characteristics of high-performance ultra-modern nanofluids are far superior. Because of its impact on the pumping needs of thermal systems, understanding the viscosity of nanofluids is crucial. Concentration and temperature effects on the dynamic viscosity of graphene (Gr) and titanium carbide (TiC) nanofluids are investigated. To synthesize nanofluids with a concentration of volume of 1% to 7%, we first dispersed Gr nanoparticles in ethylene glycol (E), then TiC in E, and finally TiC in distilled water (W), using the two-step procedure. The viscosity of these nanofluids was measured experimentally with an Ostwald viscometer between 25 and 65 °C. A correlation between nanoparticle concentration in volume and the measured nanofluids' viscosity was found. The viscosity ratio of TiC nanofluids was 1.145 and 1.712 times that of the base fluid at 1 and 7% volume concentration. In addition, raising the temperature above that of the basic fluids causes the nanofluids to become less viscous.

Keywords

Nanofluids, Graphene, Viscosity, Thermal systems, Titanium carbide

Introduction

The improved thermal properties of nanofluids have contributed to the rapid expansion of this field of study during the past decade. Nanofluids consist of particles on the nanoscale that have been evenly distributed throughout a solvent [1]. The improved thermophysical properties of the base fluid make it an ideal heat transfer liquid after going through this process. Gr and TiC are two examples of ceramic nanoparticles that exhibit amazing qualities. These characteristics include being able to withstand high temperatures without oxidising and being extremely pure, stable, and active on the surface [2]. Since they have these qualities, ceramic nanoparticles distributed in heat transfer fluids are a good choice. The viscosity increases once these nanoparticles are added to the base fluid. Due to its impact on the pumping power needed for thermal systems, viscosity is an important fluid dynamical issue. As a result, viscosity is a critical factor in the development of heat transfer apparatus [3]. However, the viscosity of nanofluids has received less attention from researchers than the thermal conductivity of nanomaterials. The experimental study of nanofluid viscosity has recently seen publication [4-6].

The viscosity of nanofluids is said to be significantly influenced by temperature and volume fraction [7]. Nanoparticle form and size, base fluid viscosity, and colloidal dispersion also have a role, as do concentration of surfactant, pH, kind of surfactant, and the process of preparing the nanofluid. Therefore, scientists attempt to investigate how these variables impact the viscosity of nanofluids. Researchers [8] have studied the impact of varying iron nanofluid concentrations at temperatures spanning 10 - 60 ˚C, using three distinct E-water fluids mixes. They found that the absolute viscosity of the 25/75/45/55 E/water mixes was 1.82, 1.96, and 2.28 times that of the water fluid, respectively, at a volume concentration of 2%. At low temperatures (275 - 283 K) and volume concentrations (0.0047 - 0.2381), researchers [9, 10] investigated the rheological properties of multi-walled carbon nanotube nanofluids in water. It has been suggested that a volume fraction of 0.0571% marks the change from Newtonian to non-Newtonian behavior. This suggests that below a concentration of 0.0571% by volume, the relative viscosity of nanofluids is rather insensitive to changes in temperature and shear rate. For nanoparticle volume fractions above 0.1428%, temperature and shear rate fluctuations cause noticeable shifts in viscosity. A solution of lanthanum oxide and water was studied experimentally to ascertain its thermal physical characteristics [11, 12]. At 323 K, the findings showed that the maximum mass concentration of nanoparticles caused a relative increase in viscosity of 10.186%. Between 25 and 70 ˚C and 0.005 and 5% by weight, the authors [13] studied the dynamic viscosity of copper oxide (CuO)/ethanol, CuO/deionized water, and CuO/E nanofluids. They discovered Newtonian dynamics applied to nanofluids and provided an explanation for this finding. When the nanoparticle mass fraction was 7% and the temperature was elevated from 25 to 70 ˚C, the findings revealed that the viscosity of solutions containing CuO, deionized water, and E fell by 69%, 66%, and 67%, respectively. Most of the research focused on oxide nanofluids.

The goal of mathematical modelling is to formulate a problem using mathematical notions. Models capture the essence of the underlying problems and help researchers collect data more efficiently. There are time and money savings compared to doing the experiment in the real world. Theoretical models, empirical models, and semi-empirical models are the three main categories of models created to predict nanofluid viscosity [14, 15]. Theoretical models are those built in accordance with established scientific principles, whereas empirical models are those formed by empirical data fitting. These “semi-empirical” models fuse together theoretical foundations with actual data. Certain theoretical model parameters are precisely determined by experimental evidence. Understanding the nanofluid’s viscosity is essential for calculating the pressure reduction across heat transferring infrastructure, which is important from an economic and energy consumption standpoint. Since the experimental determination of nanofluid viscosity is time-consuming and costly, it is vital to create models for predicting viscosity. Despite the growing body of research on nanofluids, very little attention has been paid to developing models for calculating their viscosity. There is currently no universal theoretical model that can be used to reliably predict the viscosity of nanofluids [16]. Researchers use empirical models by fitting a model to observed data from experiments. Empirical models are more likely to be in accord with experimental evidence than theoretical ones.

The reason for this disparity is because whenever theoretical models are created, simplifying assumptions are made. In addition, the model parameters used in theoretical models are often unavailable in practise. Predicting the viscosity of nanofluids is a challenging problem, yet empirical models perform exceptionally well. While there are many different nanofluids, most experimental models can only be used with one particular set of parameters. Therefore, it is important to establish a relationship for certain nanofluids. Increasing the nanoparticle concentration in Gr and TiC nanofluids leads to enhanced thermophysical characteristics. There is disagreement on the impact of volume concentration and temperature on nanofluid viscosity, and only a small number of research have employed Gr and TiC nanofluids to calculate effective viscosity. An empirical equation for the viscosity of nanofluids requires further research. Additionally, additional research will assist to gather more trustworthy data for potential future uses of nanofluids. The purpose of this research is to examine the impact of concentration of volume and temperature on the viscosity of Gr/E, TiC/E, and TiC/W nanofluids. The results of the experiments are then utilised to create a model. The hypothesized connection is tested, and its results are compared to those of established theoretical frameworks.

Experimentation

Materials and characterization

Gr and TiC nanoparticles were used in this research. Manufacturers claim an average particle size of 65 - 75 nm for the Gr nanoparticles customers have purchased. TiC nanoparticles used in this research between 20 and 50 nm in size. The primary medium was a mixture of W and E. The features of the nanoparticles are summarised in table 1 and table 2, respectively.

The amounts of nanoparticles needed to make nanofluid were determined for each volume concentration by the law of mixing formulation given as equation 1 [17, 18].

$$\varphi = \frac{\left[\frac{m_{np}}{\rho_{np}}\right]}{\left[\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}\right]} \text{ x } 100 \quad (1)$$

Where ‘φ’ is nanoparticle volume concentration, ‘ρ_{bf}’ is density of the base fluids, ‘m_{bf}’ is mass of the base fluids, ‘ρ_{bp}’ is density of the nanoparticles, and ‘m_{np}’ is mass of the nanoparticles.

Gr/E, TiC/E, and TiC/W nanofluids with volume concentrations between 1% and 7% were produced utilising a well-established two-step method [19].

The powder was added to the base fluid after being stirred for 30 min using a magnetic stirrer. We used an ultrasonic

Table 1: Detailed description of nanoparticles.

Properties	Gr	TiC
Thermal conductivity	3200 W/mK	330 W/mK
Specific surface area	30 - 60 m^2/g	> 18 m^2/g
Purity	99.99%	> 99.9%
Color	Black granules	Black
Bulk density	0.1 g/cm^3	4.93 g/cm^3

Table 2: Specification of ethylene glycol.

Properties	Range
Boiling point	197.6 °C
Density	1.214 - 1.221 g/ml
Boiling range	196 - 198 °C
Melting point	-14 °C

processor equipped with a probe with a diameter of 8 mm and a sonication power setting of 80% to homogenize the mixture and prevent the nanoparticles from clumping together. Each sample was ultrasonically agitated in a 100-cc beaker at 25 °C for 15 h. However, Gr nanoparticles will hydrolyze into aluminum hydroxide when dissolved in water. Preparation of Gr/W nanofluid was avoided due to the complexity of controlling hydrolysis of Gr nanoparticles in distilled water. There was no evidence of agglomeration or sedimentation in the nanofluids after 48 h of preparation, so continued the investigation into their properties. Zeta potential analysis was also used to study the long-term stability of nanofluids.

Rheology measurement

Nanofluid viscosities were measured using an Ostwald viscometer at different temperatures and volume concentrations. In order to determine a liquid's viscosity, this device monitors the amount of time it takes for a predetermined volume of the liquid to pass through a predetermined length of capillary tube at a predetermined temperature [20]. An Ostwald viscometer is maintained in a water bath with a temperature range of 0.5 °C. The capillary U-tube of the viscometer was filled with the test fluid, and the whole assembly was placed on a tripod in a water bath (Figure 1).

The viscometer was left in the solution for 20 min after the set temperature was reached to ensure thermal equilibrium. After being sucked into the top bulb, the test fluid was released to return to the bottom bulb by gravity. A stopwatch accurate to 0.01 sec was used to record the amount of time it took for the liquid level to move between the two markings (A and B) in the device. Multiplying the time interval by the constant

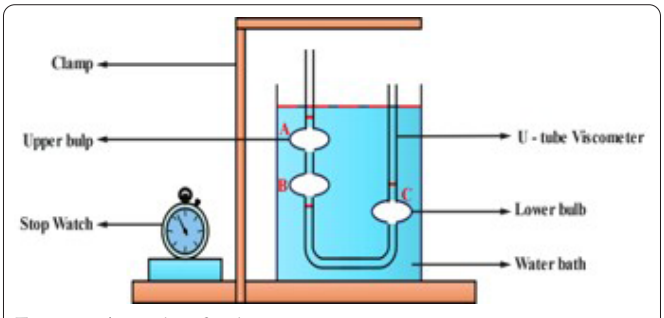


Figure 1: An outline for the viscosity measurement.

provided by the viscometer's manufacturer (Equation 2), the kinematic viscosity was calculated, whereas the dynamic viscosity was given in terms of cP (Equation 1).

$$v = k,t$$
$$v = \frac{\mu}{\rho_s} \quad (2)$$

Where 'v' is kinematic viscosity (cSt), 'k' is viscometer constant, 't' is flow time (sec), 'μ' is dynamic viscosity (cP), and 'ρ' is density of the liquid specimen (g/cm^3).

The nanofluid samples were heated in a water bath to different temperatures up to 60 °C for evaluation above 35 °C. The values were averaged from five separate sets of measurements performed at each temperature (to account for any experimental variation). By taking readings at 25, 45, 55, and 65 °C, we were able to verify that our viscometer was properly calibrated for our tests. To validate our measurements, we looked up the W viscosity in the database maintained by the International Association for the Properties of Water and Steam. Maximum W and E percentage errors were determined to be 3% and 7%, respectively.

Uncertainty analysis

The uncertainty is calculated by determining the inaccuracy of the measurements, and it is a measure of the 'quality' of an experimental result. The precision of an experiment may be calculated with the use of an uncertainty analysis. Thus, the experimentally reported precisions were used to symbolise the degree of uncertainty. The experimental error was estimated using equation 3.

If Z depends on 'n' linear constants, then $Z = F(x_1, x_2,\ldots, x_n)$, the error F due to x_1 can be estimated as $dF_1 = \frac{\partial F}{\partial x_1} dx_1$.

As a result, we may evaluate the function Z's uncertainty as [6].

$$dz = \left[\left(\frac{\partial F}{\partial x_1}\right)^2 dx_1^2 + \left(\frac{\partial F}{\partial x_2}\right)^2 dx_2^2 + \ldots + \left(\frac{\partial F}{\partial x_n}\right)^2 dx_n^2\right]^{0.5} \quad (3)$$

Where 'dz' is Uncertainty of function 'Z', 'dx_i' is Uncertainty of parameter x_i, and '$\frac{\partial F}{\partial x_i}$' is Partial derivative of F with respect to parameter x_i.

Nanofluid viscosity measurements were shown to have an absolute maximum error of 7%, suggesting the reliability of the reported values. Einstein's model, the most well-known classical viscosity model, works best for extremely tiny, stiff, spherical particles with a volume concentration of less than 2 percent. Here is how the model is specified.

$$\mu_{nf} = (1 + 2.5\varphi)\,\mu_{bf} \quad (4)$$

Brinkman (1952) simplified the mathematics of the Einstein equation such that it applies at particle concentrations of up to 4% by volume. This model may be stated as follows.

$$\mu_{nf} = \frac{1}{(1-\varphi)^{2.5}}\,\mu_{bf} \quad (5)$$

Viscosity of nanofluids impregnated with spherical particles may be calculated with the use of a mathematical equation proposed by Batchelor (1977). The model has the following shape, taking into account the Brownian motion of nanoparticles and their interactions.

$$\mu_{nf} = \mu_{bf}\left(1 + 2.5\varphi + 6.2\varphi^2\right) \quad (6)$$

Where 'μ' is dynamic viscosity, 'φ' is solid volume concentration, '*nf*' is nanofluids, and '*bf*' is base fluids.

Results and Discussion

Stability of nanofluids

At 25 °C, the absolute zeta potential of Gr/E, TiC/E, and TiC/W nanofluids at 1, 3, and 5 vol.% concentrations was determined. Figure 2 shows the results of scatter plot. Above 50 mV indicates moderate stability, 70 mV indicates fair stability, and 80 mV indicates exceptional stability for a suspension. The results of this investigation show that the nanofluids are stable, with some evidence of settling, at absolute zeta potential levels between 70 and 76 mV.

Impact of concentration of volume

Figure 3 displays the relationship between the volume concentration of nanoparticles and the viscosities of Gr/E, TiC/E, and TiC/W nanofluids. According to the data, the viscosity improved at higher concentration levels. For percentage volume between 1% and 7% at 25 °C, the viscosity of Gr/E nanofluids was in the limits of 21.9 to 30 cP, TiC/E nanofluids were in the range of 21.7 to 29 cP, and TiC/W nanofluids were in the range of 1.385 to 1.73 cP. Thus, at 25 °C, increasing the nanoparticle loading from 1% to 7% increased the viscosities by 51% for the Gr/E nanofluid, 27% for the TiC/E nanofluid, and 40% for the TiC/W nanofluid.

The observed viscosity is confirmed to be highly volume concentration dependent for nanoparticles. When the viscosity of the fluid used to suspend the solid particles increases, the friction between the particles and the fluid also increases. As a result, the concentration of particles and hence the viscosity rise along. In addition, higher concentrations increase the number of particle-fluid interactions, which can lead to particle aggregation owing to van der Waals forces among particles and, ultimately, higher viscosity. Table 3 displays these results, which are compared to those of the current investigation for TiC/W nanofluid. Viscosities of 12.144 and 10.171 cP were reported at a volume percentage of 1% for E-based TiC, while we recorded range of 13.56 and 10.36 cP at temperatures of 45 and 55 °C, correspondingly.

Figure 4 displays, for the nanofluids outlined above, the relationship between volume concentration and the proportion of nanofluid to water fluid viscosities at 25 °C. The solids-to-volume ratio grows more viscous as the solid's concentration

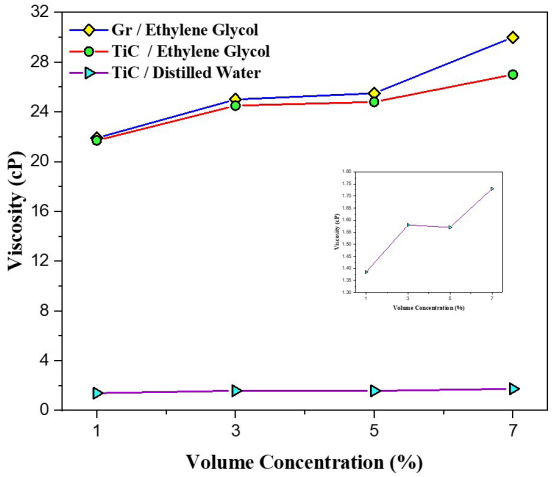


Figure 3: Viscosity of AIN/EG, TiC/E and TiC/W nanofluids for varying nanoparticle volume concentrations.

Table 3: Experimental dynamic viscosity of TiC/W.

Nanofluid	TiC/W
Concentration	1 - 7 vol
Viscosity	0.803 - 1.21 cP (at 28 °C)

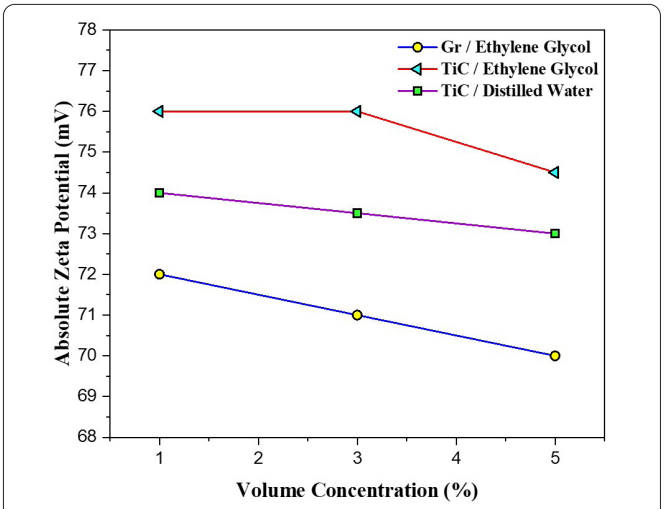


Figure 2: Zeta potential for variant concentrations of volume of Gr/E, TiC/E and TiC/W nanofluids.

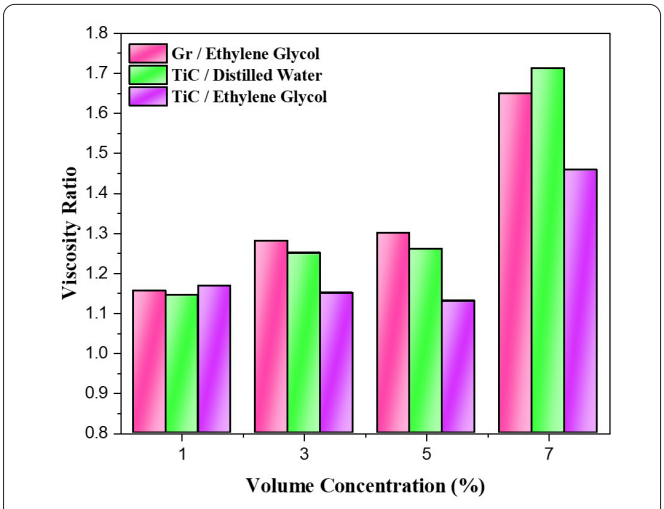


Figure 4: Viscosity ratio for AIN/EG, TiC/E and TiC/W nanofluids for varying nanoparticle volume concentrations.

grows. The ratio of viscosity to the base fluid was increased by 1.156 and 1.649 times for Gr/E nanofluids at 1 and 7% volume concentration. It's worth mentioning that other authors have observed results comparable to those found in this work when utilising Gr dispersed in E at a 7% nanofluid volume concentration. At 20 ˚C, the nanofluid's viscosity increased by about 76%; in this investigation, it increased by 57%. At a concentration of 7% volume, the viscosity ratio of TiC/E nanofluids was 1.168 times that of the base fluid, and at a concentration of 7% volume, the ratio was 1.458 times that of the base fluid. When the volume concentration reached 7%, the ratio of the viscosity of the TiC/W nanofluids to the base fluid was 1.145 and 1.71, respectively. However, the integration of TiC nanoparticles at a volume concentration of 4% decreased the viscosity of TiC/W, which may imply that the kind of base fluid affects the nanofluid's viscosity.

Similar findings about a change in the rate of rise of nanofluid viscosity were reported by authors. A maximum rise in viscosity at 25 ˚C was seen after adding a 3 wt.% fraction of TiC nanoparticles; the rate of increase after that was not obvious. Nanofluids were also shown to have the lowest rise in viscosity between the volume concentrations of 2% and 3% Gr/E and 3% TiC/E. Because of the little increase in viscosity that nanofluids display, a volume concentration of 1 - 3% is preferred when using Gr/E and TiC/E in engineering applications. For the investigated volume concentrations, the average viscosity ratios for Gr/E, TiC/E, and TiC/W nanofluids were 1.057 ± 0.227, 0.913 ± 0.193, and 0.974 ± 0.182. As a result, TiC/E was found to have the most favorable viscosity ratio. In conclusion, a higher fluid pressure drop suggests a greater pumping power when solid particles are suspended in a base fluid. Because of the potential damage that excessive particle loading might cause to a heat exchanger, it is best to prevent it.

Figure 5 displays the results of an evaluation among the experimental data and the predictions of previously suggested models. At a concentration of 1% by volume, the measured viscosities of nanofluids are found to be quite comparable.

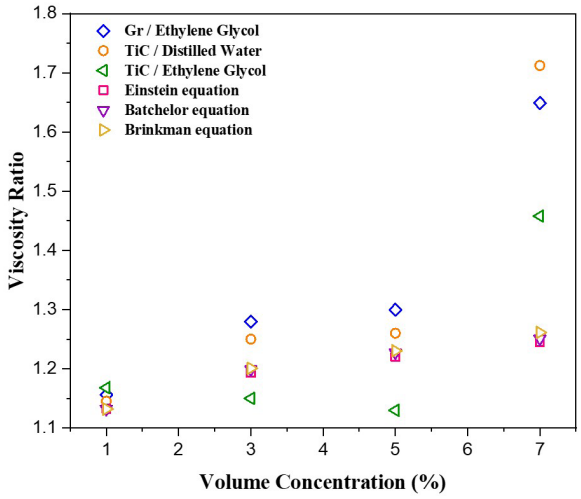


Figure 5: Comparison between viscosity ratio for Gr/E, TiC/E and TiC/W nanofluids and various theoretical models.

However, these models significantly under-estimate the experimental evidence of viscosity as the concentration increases. Some studies have found the same pattern. Table 4 summarises the results of an evaluation of these models' performance based on the percentage error they exhibit when compared to experimented data using equation 8.

$$\text{Percentage error}(\%) = \frac{|\text{Theoretical value} - \text{Experimental value}|}{\text{Theoretical value}} \times 100 \quad (7)$$

For all nanofluids, the standard deviation of the percentage error at a concentration of 1% by volume is 2.752%. This happens because Brownian motion, intermolecular interactions, and dispersion methods are not accounted for in the models, which are only correct for low-density particle suspensions. Cluster formation during nanoparticle suspension in fluids may also contribute significantly to the nanofluids' enhanced viscosity. For the Gr/E nanofluid, the percentage error ranged from 2.740% to 39.883%; for the TiC/E nanofluid, it was between 0.437 and 14.57%; and for the TiC/W nanofluid, it was between 1.032 and 27.581 %.

Table 4: Viscosity ratio for Gr/E, TiC/E and TiC/W nanofluids.

Vol conc (se)	Experimental result	Einstein model	Percent error (%)	Batchelor model	Percent error (%)	Brinkman model	Percent error (%)
	Gr/E						
1	1.261	1.1236	2863	1.1335	2.742	1.1336	2.752
3	1.32	1.214	14975	1.1992	14.263	1.2011	15.463
5	1.5	1.26	15.030	1.2286	14.552	1.2341	15.849
7	1.752	1.258	39.896	1.2612	37.894	1.2624	39.433
	TiC/E						
1	1.172	1.1334	0.462	1.1335	0.456	1.1420	0.442
3	1.26	1.199	0.435	1.1995	0.024	1.2041	5.864
5	1.29	1.31	13.006	1.2286	12.11	1.2311	12598
7	1.466	1.256	14566	1.2512	13.322	1.2624	12.935
	TiC/W						
1	1.14611	1.1332	1.052	1.1355	1.042	1.1326	1.044
3	1.31	1.195	14099	1.1995	13.006	1.2011	13.491
5	1.38	1.25	12975	1.2275	12.218	1.2305	11.915
7	1.712379	1.256	27.585	1.2519	20.262	1.2624	25.711

Model development

Results for the viscosity of Gr, TiC/E, and TiC/W nanofluids are shown in figure 5, and it can be observed that the theoretical model underestimated these values. For these nanofluids, we determined the unknown correlations between volume, concentration, and temperature. Using the solver add-in for Excel, the experimental data was mapped to the six-factor (a, b, c, d, e, and f) model. The solution adjusts the parameter so that the difference between the observed and anticipated values is minimised by computing the sum of squared errors.

$$\frac{\mu_{nf}}{\mu_{bf}} = a\varphi^{e} + b\varphi^{f} + c\varphi + d\left(\frac{\log T}{\varphi}\right) \quad (8)$$

Where 'T' is temperature (°C), 'φ' is concentration of volume (vol.%), 'μ_{nf}' is base fluid viscosity in cP, and 'μ_{bf}' is nanofluid viscosity in cP.

Table 5 provides the ideals of a, b, c, d, e, and f that may be used to forecast the viscosity ratio of Gr/E, TiC/E, and TiC/W nanofluids at varying concentrations. The hypothesised connection is quite accurate, as seen by the high values of the regression coefficient, R^2 for Gr/E, TiC/E, and TiC/W, respectively (0.988, 0.972, and 0.948).

Effect of temperature

The temperature-dependent viscosities of Gr/E, TiC/E, and TiC/W nanofluids with various concentrations of nanoparticles are shown in figure 6. The plots show that when the temperature of the nanofluids increased, the dynamic viscosity decreased dramatically. Viscosity was highest at 25 °C across the board for all volume concentrations tested (1 - 7%). Nanofluids with a volume content of 0% and 7% nanoparticles showed a steady reduction in viscosity from 25 to 65 °C. Figure 6 a shows that at a concentration of 1% by volume, the dynamic viscosities of TiC/W nanofluids drops from 1.36 cP to 1.07 cP when the temperature is raised from 25 to 65 °C. TiC/W nanofluid's dynamic viscosity drops from 1.775 cP at 7% volume concentration to 1.346 cP as temperature rises from 25 to 65 °C. This means that at 1 and 7% volume concentrations, the dynamic viscosity of TiC/W nanofluids reduces by 28 and 30% as the temperature rises.

At a 7 vol.% concentration and 65 °C, TiC/W nanofluids achieve their maximal enhancement of 63%. In addition, at 7 vol.% concentration and 65 °C, Gr/E and TiC/E nanofluid may achieve maximal viscosity enhancements of up to 176 and 108%, respectively. Because the intermolecular interactions between the base fluid and the nanoparticle surface and the interparticle forces within the fluid both decrease with increasing temperature, the viscosity of the fluid increases. This temperature effect on nanofluid viscosity is widely reported in the scientific literature. Researchers have found a maximum increase in viscosity of 129% at 3.0 vol.% loading for Fe_3O_4/H_2O nanofluids at 55 °C. The dynamic viscosity was found to increase by as much as 116% at 45 °C when the solid volume fraction of SiO_2/EG was raised from 0.1 to 3%, as demonstrated by the aforementioned researchers. These results are consistent with the observation that at a volume concentration of 3% and a temperature of 65 °C, the dynamic viscosity of Gr/E increased by as much as 116%. When the particle volume percent of MgO-EG is 0.03 and 0.05, respectively, the relative viscosity increases by 15.1% and 29.2%. TiC/E nanofluids were found at similar concentrations of 14.4 and 28.8% in the present study.

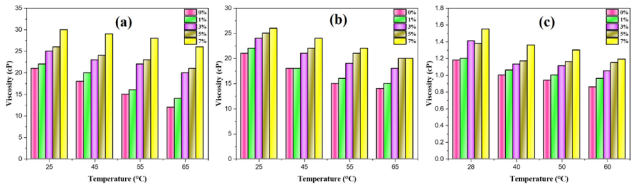


Figure 6: Viscosity changes for **(a)** Gr/E, **(b)** TiC/E, and **(c)** TiC/W nanofluids as a function of temperature.

Conclusions

Gr/E, TiC/E, and TiC/W have their viscosity measured experimentally. Experiments with 1, 3, 5, and 7% nanoparticles by volume were conducted between 25 and 65 °C. Below is a summary of the findings.

The concentration of nanoparticles in the fluid and the temperature both had an effect on the fluid's viscosity.

- The average viscosity ratios for Gr/E, TiC/E, and TiC/W nanofluids at 25 °C were 1.0690.235, 0.927.0186, and 0.984.196, respectively. A 1% increase in nanoparticle concentration in volume has no discernible effect on the nanofluid's viscosity ratio. The effects of nanoparticles increased above a concentration of 1% by volume; At a 7 vol.% concentration, TiC/W nanofluid exhibited a dynamic viscosity ratio of 1.712, whereas Gr/E nanofluid registered 1.649 and TiC/E registered 1.348.
- The viscosity of a nanofluid may be adjusted in a wide range by playing with the volume and the temperature. Therefore, both volume concentration and temperature must be taken into account in nanofluid applications.

Table 5: Coefficients of regression equation.

Nanofluids	a	b	c	d	e	f	R^2
Gr/E	0.128592	-0.92104	1.052945	0.107758	2.447473	1.061292	0.998
TiC/E	1.211503	0.013980	0.103074	-0.10900	-0.20545	0.087713	0.972
TiC/W	0.440634	-2.71033	3.127273	0.14736	1822002	1.317039	0.948

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None.

Conflict of Interest

None.

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