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Research Article

Prandtl Number and Viscosity Correlations of Titanium Oxide Nanofluids

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Many features of nanofluids, such as the Prandtl number and viscosity, are researched as the number of studies conducted in the field of nanofluids increases. Observations on the Prandtl number and viscosity of titanium oxide nanofluids are made in this study. These observations are made at low concentrations of titanium oxide nanoparticles and temperatures ranging from 30.4°C to 70.4°C. Novel correlations for viscosity and Prandtl number as functions of temperature have been developed and compared to the previously published models for Prandtl number and viscosity. The results indicate that titanium oxide-ethylene glycol nanofluid has a greater viscosity and Prandtl number than all other titanium oxide nanofluids observed in the study at 0.01 nanoparticle concentration. The results on viscosity and Prandtl number for the new correlations fall within the same range as those found in the literature, indicating that the new correlations introduced as functions of temperature in this study can be used in future research to establish viscosity and Prandtl number calculations for the different types of nanofluids at specific temperatures.

1. Introduction

As nanoparticles are added to base fluids such as water, glycols, oils, and refrigerants to generate nanofluids, the thermophysical properties of the resulting fluids improve. These nanofluids are utilized in several industrial applications. The research topic on nanofluids has advanced significantly as scientists have been interested in the manufacture of these specialized fluids that contain nanoparticles. As it was discovered that nanofluids possess increased thermophysical characteristics, curiosity emerged. Various nanoparticles have been studied to demonstrate the validity of the tested hypotheses. In this article, the nanofluid viscosity and Prandtl number of titanium oxide-ethylene glycol (40%)/water (60%), titanium oxide-ethylene glycol nanofluid viscosity and Prandtl number, and titanium oxide-water nanofluid viscosity and Prandtl number are analysed. Observations are also made about the viscosity and Prandtl numbers on their respective base fluids, specifically the enhancement of viscosity and Prandtl number at varied nanoparticle concentrations of 0.004, 0.006, 0.008, and 0.01. It is vital to evaluate how high or low the Prandtl number can be, as a greater Prandtl number indicates a higher viscosity of the nanofluid, while a lower Prandtl number indicates a lower viscosity of the nanofluid. The titanium oxide nanofluids, at the measured nanoparticle concentration, have the potential for usage in numerous applications due to a minor increase in viscosity for the selected nanoparticle concentrations. The Prandtl number depends on the nanofluid's specific heat, viscosity, and thermal conductivity. In addition to detecting the Prandtl number and viscosity of nanofluids using the aforementioned published models, we examine new correlations for Prandtl number and viscosity and compare them to previously published models. It is important to evaluate the effects of temperature on the thermophysical properties of nanofluids, as determined by a thorough analysis of the relevant literature. The correct analysis of the thermophysical and rheological properties that nanofluids should possess when utilized in a variety of industrial applications necessitates the development of novel correlations that involve temperature. Temperature plays a significant role in the thermophysical characteristics of nanofluids. Nanofluids are analysed at a variety of temperatures and nanoparticle concentrations to identify the optimal outcomes. Numerous experiments have been conducted in which researchers have been able to observe these findings measured at specific temperatures using measuring devices or theoretical models; however, there is a gap in the literature where more correlations, particularly correlations as functions of temperature, are required to analyse the nanofluids at specific temperatures using correlations. Hence, theoretical models and experimental investigations may be predicted with more ease, and more precise results can be acquired. This study provides more recent relationships between the Prandtl number and viscosity.

2. Literature Review

Viscosity and the Prandtl number were examined by several experts in their respective fields, and their work and findings are discussed in Table 1.

3. Data Reduction

The Prandtl number depends on the nanofluid's thermal conductivity, specific heat, and viscosity. Equation (1a) depicts the formula used by Tiandho et al. [21] and other researchers to analyse the nanofluid Prandtl number in scientific literature.

$$P_r = \frac{\mu C_p}{k}. \tag{1a}$$

For nanofluid computations, equation (1a) can be rewritten as shown in the following equation:

$$P_{r,\mathrm{nf}} = \frac{\mu_{\mathrm{nf}} C_{p,\mathrm{nf}}}{k_{\mathrm{nf}}}, \tag{1b}$$

where $P_{r,nf}$, μ_{nf}, $C_{p,nf}$, and k_{nf} are the nanofluid Prandtl number, nanofluid viscosity, and nanofluid specific heat, respectively. In this study, the Prandtl number and viscosity of three nanofluids are measured at temperatures ranging from 30.4°C to 70.4°C. The titanium oxide nanoparticles are combined with ethylene glycol (40%)/water (60%), ethylene glycol, and water as the basis of fluids. Equation (2) of the Einstein model is the most popular model for calculating nanofluid viscosity. Manikandan and Baskar [16] were among the researchers who utilised this model.

$$\mu_{\mathrm{nf}} = \mu_{\mathrm{bf}}(1 + 2.5\varnothing), \tag{2}$$

where μ_{nf}, μ_{bf}, and $\varnothing$ indicate the viscosity of the nanofluid and the base fluid, respectively, and $\varnothing$ represents the nanoparticle concentration. The thermophysical properties are observed using ASHRAE (2017) Handbook-Fundamental (SI).

3.1. Viscosity and Prandtl Number's Base Fluid Properties and Correlations.

Prior to introducing the new nanofluid correlations for Prandtl number and viscosity, it is crucial to have examined the base fluid properties for the nanofluid analysis, as base fluids form the basis of the new correlations in this study. The base fluids are used to compare the findings obtained using both the theoretical models and the novel correlations to determine the difference between utilizing nanoparticles to enhance thermophysical properties and not using them.

Table 2 provides an examination of the base fluids. The correlations of base fluids are explored at temperatures ranging from 30.4°C to 70.4°C.

4. New Correlations for Viscosity and Prandtl Number for Nanofluids as Functions of Temperature

This section's study is based on the latest correlations between the viscosity and the Prandtl number. The correlations are used for calculating the viscosity and Prandtl number of nanofluids. The correlations are also reported for the range of temperatures between 30.4, and 70.4 degrees Celsius. In addition to its usage in titanium oxide nanofluid investigation, the novel correlations can be utilized to compute the viscosity and Prandtl number of different nanofluids at various temperatures.

4.1. New Viscosity Correlation as a Function of Temperature.

The equation in 4.1 represents the new link between viscosity and temperature, where μ_{nf}, μ_{bf}, $\varnothing$, and T represent the viscosity, base fluid, nanoparticle concentration, and temperature of the nanofluid.

$$\boldsymbol{\mu_{\mathrm{nf}} = \mu_{\mathrm{bf}}(1 + 3.5\varnothing) - 0.035\mu_{\mathrm{bf}}\mathrm{T}\varnothing}. \tag{3}$$

4.2. New Prandtl Number Correlation as a Function of Temperature.

The equation in 4.2. represents the new Prandtl number correlation, where $P_{r,\mathrm{nf}}$, μ_{bf}, ρ_p, k_p, $C_{p,\mathrm{bf}}$, k_{bf}, $\varnothing$, $C_{p,p}$, ρ_{bf}, and T represent the nanofluid Prandtl number, base fluid viscosity, nanoparticle density, nanoparticle thermal conductivity, base fluid specific heat, base fluid thermal conductivity, nanoparticle concentration, nanoparticle specific heat, base fluid density, and temperature, respectively. This new association between the Prandtl number and viscosity is applicable to the research of numerous nanofluids that require examination.

Table 1: A summary of the literature work done by researchers on the Prandtl number and viscosity.

Authors	Base fluid	Nanoparticle	Nanoparticle concentration	Results obtained
Rudyak et al. [1]	Distilled	Zirconia, aluminum, silicon, and titanium	1% and 8% by volume	The Prandtl number increased with increasing nanoparticle concentration and dropped with decreasing nanoparticle size [1]
Ganesh et al. [2]	Water and ethylene glycol	Gamma aluminum oxide	0.05, 0.1, 0.15, and 0.2 by volume	A velocity profile rise was noticed [2]
Raza et al. [3]	Water	Copper		Nanoparticle concentrations and Prandtl number influence the velocity profile [3]
Kim et al. [4]	Distilled water	Aluminum oxide	0.25%, 0.5% and 1% wt%	Found a decline in Prandtl number when nanoparticle concentrations rose [4]
Özdemir and Öğüt [5]	Water/ethylene glycol ethylene glycol concentration from 0% to 60%	Aluminum oxide	0% to 1.5%	The Prandtl number grew as the concentration of ethylene glycol likewise increased [5]
Al-Amir et al. [6]	Water	Silver	$0 < \phi < 0.2$ by volume	Conclusion: the Nusselt number increased as the Prandtl number increased [6]
Mikkola et al. [7]	Water	Aluminum oxide, micelles, polystyrene, and silicon oxide	0.1% to 1.8% volume percentage	In comparing nanofluids, the significance of the Prandtl number varies. The Nusselt number remained negligible since the Prandtl number was considered [7]
Sundar et al. [8]	Oil magnetic	Ferrous oxide	0.05% to 0.5%	The Prandtl number of nanofluid is 1.52 times greater at 30°C and 1.6 times greater at 60°C compared to the base fluid. With increasing temperature, the Prandtl number decreased [8]
Veera Krishna [9]	Water	Aluminum copper	0.05%, 0.1%, 0.15%	Raising the Prandtl number decreased the temperature and thickness of the boundary layer [9]
Zargartalebi et al. [10]				When the Prandtl number increased, a reduction in the thickness of the thermal boundary layer was noticed [10]
Nasrin [11]	Water	Aluminum oxide	2%	The rise in the Prandtl number enhanced the heat transfer rate, but it decreased the collector’s efficiency [11]
Nabil et al. [12]	Water/ethylene glycol (60 : 40)	Titanium oxide-silicon dioxide (50 : 50)	0.5% to 3.0%	With an increase in temperature, viscosity was shown to diminish [12]
Yu et al. [13]	Water	MWCNT	0.0047%, 0.023%, 0.0571%, 0.1428%, and 0.2381%	Results indicated a small increase in viscosity when temperature rose over the critical threshold [13]
Shah et al. [14]	Ethylene glycol	Reduced graphene oxide	0.02%, 0.04%, and 0.05%	Reduced graphene oxide/ethylene glycol nanofluid viscosity was lowered by 22% [14]
Iqbal et al. [15]	Water	Titanium oxide	0.1%, 0.25%, 0.5%, and 0.75%	Viscosity rose with increasing nanoparticle concentrations [15]
Manikandan and Baskar [16]	Water/ethylene glycol at 40 : 60, 50 : 50, and 30 : 70	Titanium oxide zinc oxide	0.2 to 1.0 by volume	Found an increase in viscosity after adding nanoparticles to the basic fluids [16]

Table 1: Continued.

Authors	Base fluid	Nanoparticle	Nanoparticle concentration	Results obtained
Samylingam et al. [17]	Ethylene glycol (40%)/water (60%)	Cellulose nanocrystal CNC	0.1%, 03%, 0.5%, 0.7%, 0.9, 1.1, and 1.5%	Measurements revealed a rise in viscosity as nanoparticle concentration rose, with the lowest viscosity measured at 70°C for a concentration of 0.1% by volume [17]
Kumar et al. [18]	Water	Ceric oxide zinc oxide	0.5% to 2.0% by volume	Temperature led to an increase in viscosity. The ceric oxide nanofluid displayed a greater rise in viscosity compared to the zinc oxide nanofluid [18]
Żyła et al. [19]	Ethylene glycol	Nanodiamond	0.01 to 0.1 by volume	It was noticed that viscosity increased whenever nanoparticle concentrations were raised [19]
Zheng et al. [20]	Water	Copper oxide, iron oxide black, aluminum oxide, and silicon carbide	0.05%, 0.1%, 0.5%, and 1.0%	An observation was made of the rise in viscosity [20]

Table 2: Viscosity and Prandtl number base fluid correlations.

Base fluid properties	Water	Ethylene glycol	Ethylene glycol (40%)/water (60%)
Viscosity (mPa.s)	$\mu_{bf} = 1.0461 - 0.0095T$ $R^2 = 0.9762$	$\mu_{bf} = 19.681 - 0.2293T$ $R^2 = 0.9529$	$\mu_{bf} = 3.0648 - 0.0311T$ $R^2 = 0.975$
Prandtl number (–)	$P_{r,bf} = 7.3418 - 0.0707T$ $R^2 = 0.9723$	$P_{r,bf} = 187.99 - 2.161T$ $R^2 = 0.9529$	$P_{r,bf} = 26.048 - 0.2669T$ $R^2 = 0.9719$

$$\mathbf{P_{r,nf}} = \frac{\mu_{bf}\rho_p k_p\left[C_{p,bf}(1+2\varnothing) + \left(C_{p,p}\varnothing/\rho_{bf}\right)\left(1-4\rho_p\varnothing+4\rho_p\varnothing T\right) - \left(0.035\rho_p\varnothing^2 T/\rho_{bf}\right)\right]}{k_{bf}\left[T\left(0.0002\rho_p+0.0012\rho_p\varnothing-0.0002T-k_p+k_p\varnothing\right)+k_p\rho_p(1+5\varnothing)\right]}. \quad (4)$$

5. Comparison of Theoretical Models with New Correlations for Viscosity and the Prandtl Number

In the analysis, the models described in Sections 3 and 4 are utilized. Results for titanium oxide-ethylene glycol (40%)/water (60%) nanofluid, titanium oxide-ethylene glycol nanofluid, and titanium oxide-water nanofluid are presented in Section 5.

5.1. Viscosity Comparison Results

5.1.1. Titanium Oxide-Ethylene Glycol (40%)/Water (60%) Nanofluid Viscosity Shown in Figure 1

5.1.2. Titanium Oxide-Ethylene Glycol Nanofluid Viscosity Shown in Figure 2

5.1.3. Titanium Oxide-Water Nanofluid Viscosity Shown in Figure 3

5.2. Prandtl Number Comparison Results

5.2.1. Titanium Oxide-Ethylene Glycol (40%)/Water (60%) Nanofluid Prandtl Number Shown in Figure 4

5.2.2. Titanium Oxide-Ethylene Glycol Nanofluid Prandtl Number Shown in Figure 5

5.2.3. Titanium Oxide-Water Nanofluid Prandtl Number Shown in Figure 6

6. Discussion of Results

6.1. Prandtl Number. In accordance with the observations made in Sections 3–5, the Prandtl number for the titanium oxide-ethylene glycol (40%)/water (60%) mixture at various temperatures is 19 at 30.4°C, as shown in Figure 4. The Prandtl value increases by a small proportion in both theoretical and new correlation results. At 30.4°C, the Prandtl number for titanium oxide-ethylene glycol is shown to range from 137 to 147 in Figure 5. In Figure 6, the Prandtl number for titanium oxide-water nanofluid ranges from 5.50 to 5.79 at 30.40 degrees Celsius. The Prandtl number of pure ethylene glycol is greater than that of water and ethylene glycol/water mixtures. Observing the various nanofluids, the Prandtl number increases as 0.004, 0.006, 0.008, and 0.01 nanoparticle concentrations are added to the basic fluids. Yet, as the temperature increases, the Prandtl number similarly falls. In both the theoretical formula for the Prandtl number and the new correlation model, it can be observed that as the viscosity increases, the Prandtl number also increases. As the temperature of the nanofluid increases, the viscosity of the nanofluid lowers, causing the Prandtl number to fall as well. The basic fluids have a lower measured Prandtl number than the nanofluids. Compared to ethylene glycol (40%)/water (60%) base fluid and water base fluid, ethylene glycol has a high Prandtl number. The Prandtl number increases ranging from 1.4% to above 3.45% for the titanium oxide-ethylene glycol (40%)/water (60%) nanofluid, from 2.4% to 5.8% for the titanium oxide-ethylene glycol nanofluid, and from 1.1% to 2.6% for the titanium oxide-water nanofluid, with reference to the base fluids. Moreover, the Prandtl number determines the thickness of the boundary layer. The greater the Prandtl number, the greater the nanofluid's high viscosity, which causes nanofluid flow constraints when the nanofluid thickens due to its high viscosity. Kho et al. [22] came to the conclusion that when the Prandtl number increased, the temperature profile continued to decrease.

6.2. Viscosity. When the concentration of nanoparticles increases, the viscosity of titanium oxide nanofluids increases. Considering the previous Sections 3–5, the viscosity increases for all the titanium oxide nanofluids are minimal. In the fluid analysis, it is essential that the viscosity is kept low. Adding nanoparticle concentrations to nanofluids increases their viscosity. Yet, as demonstrated in Figures 1–3, the viscosity increases slightly when nanoparticle concentrations of 0.004, 0.006, 0.008, and 0.01 are added to a solution. Viscosity increases slightly by fractions of percentage points in all the detected nanofluids, indicating that the necessary results in nanofluid analysis can be obtained. Among the thermophysical parameters of nanofluids, such as thermal conductivity, specific heat, and density, viscosity increases less than thermal conductivity, specific heat, and density do at the same nanoparticle concentrations. Maintaining a low viscosity is a desirable outcome in the fluid analysis and makes nanofluids even more suitable for

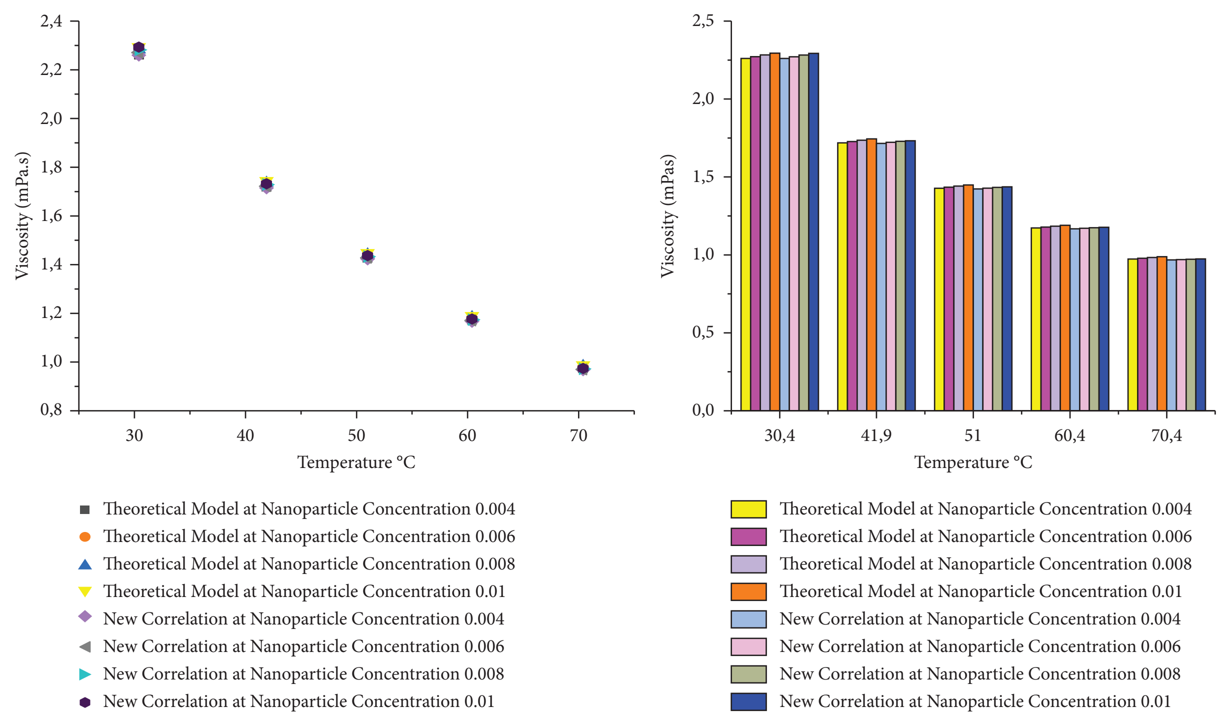

Figure 1: Comparison of titanium oxide-ethylene glycol (40%)/water (60%) nanofluid viscosity theoretical model and new correlation.

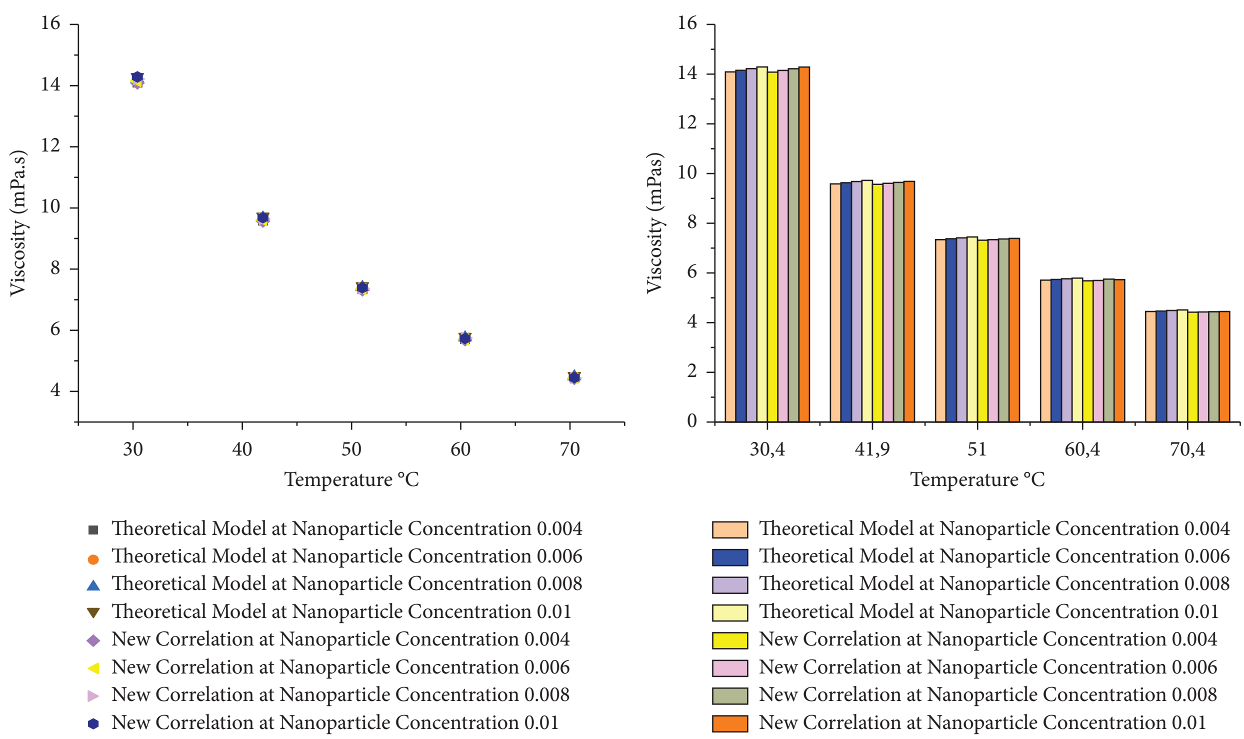

Figure 2: Comparison of titanium oxide-ethylene glycol nanofluid viscosity theoretical model and new correlation.

industrial applications. This is supported by the viscosity graphs and results presented in the study. Viscosity plays a significant role in fluid movement, and it is always preferable for the fluid to have a low viscosity. All the base fluids containing Titanium oxide nanoparticle concenrations of 0.004 have the lowest viscosity as seen in the study. Considering the selected titanium oxide nanoparticle concentrations and how the viscosity increases slightly, titanium oxide nanofluids at lower nanoparticle concentrations could be considered for use in a variety of applications, and careful consideration should also be given to titanium oxide water-based nanofluid, as the addition of higher nanoparticle

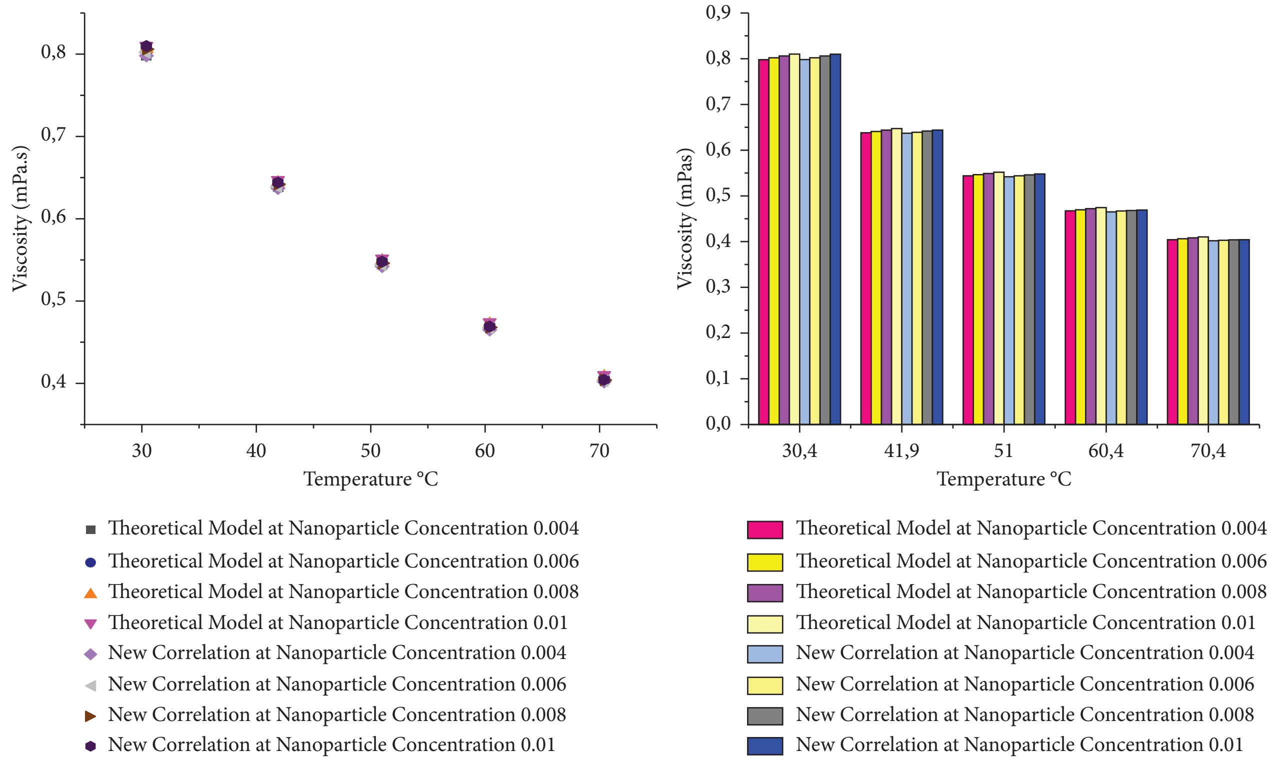

Figure 3: Comparison of titanium oxide-water nanofluid viscosity theoretical model and new correlation.

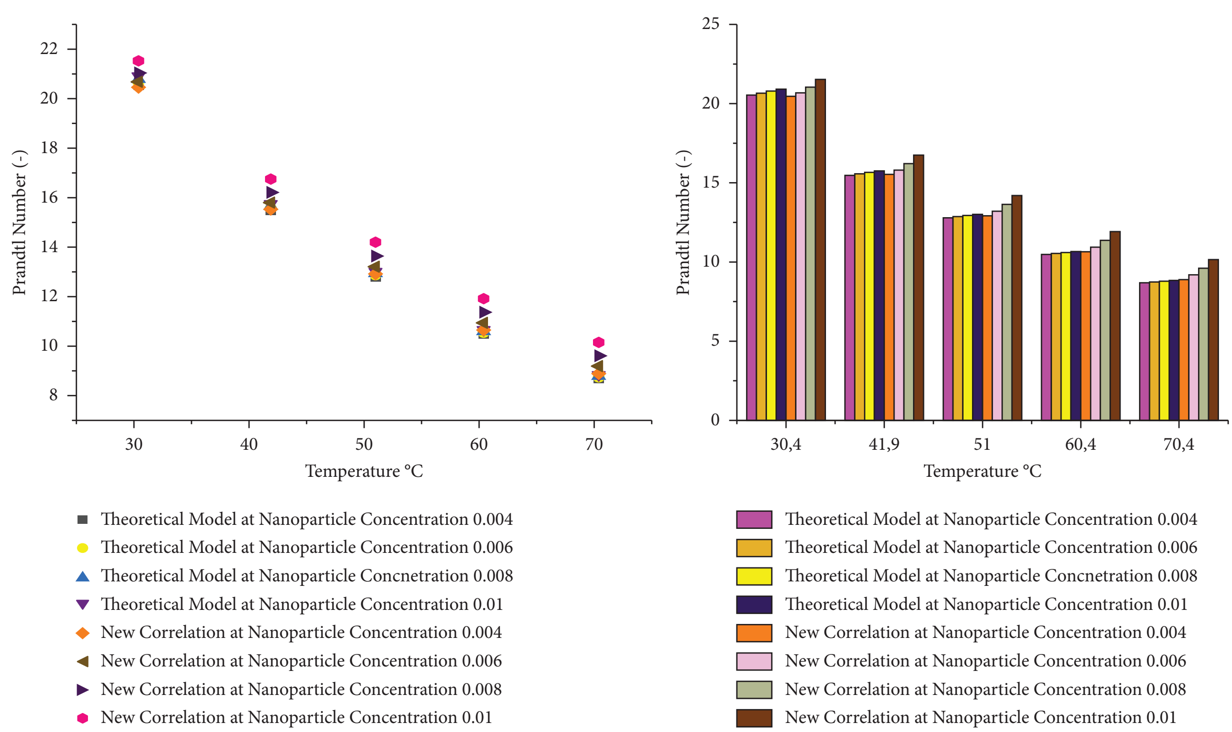

Figure 4: Comparison of titanium oxide-ethylene glycol (40%)/water (60%) nanofluid Prandtl number theoretical model and new correlation.

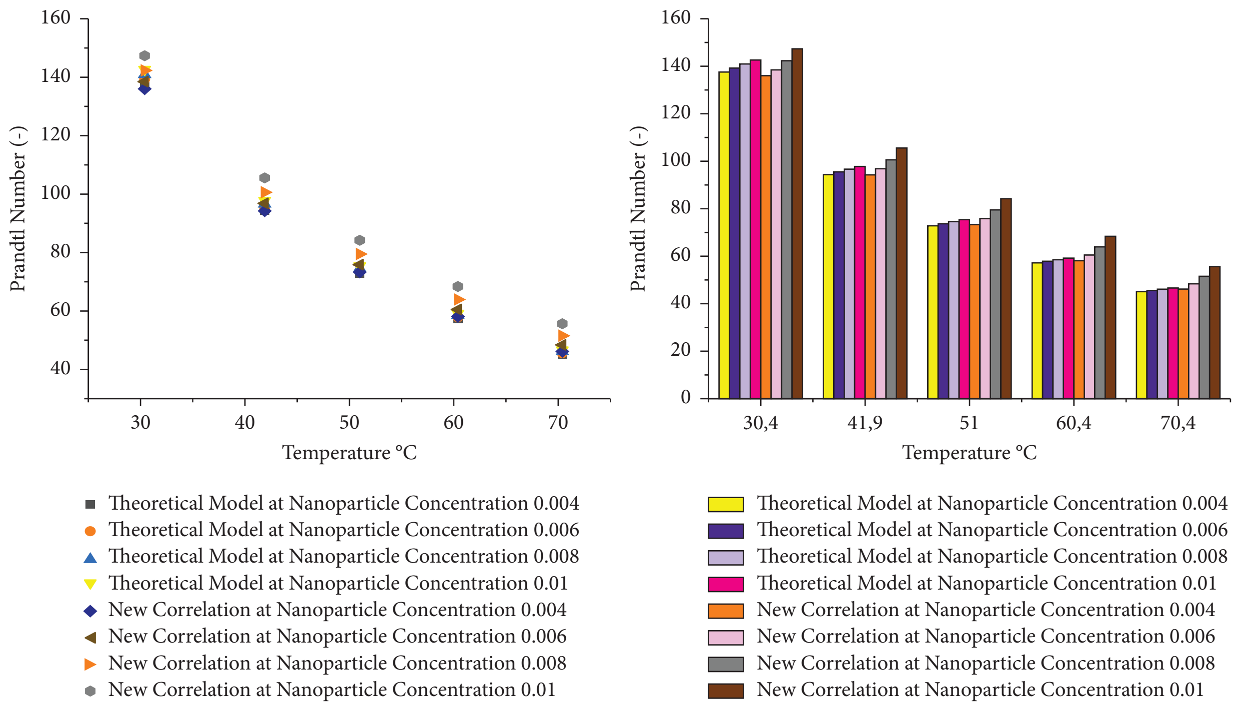

Figure 5: Comparison of titanium oxide-ethylene glycol nanofluid Prandtl number theoretical model and new correlation.

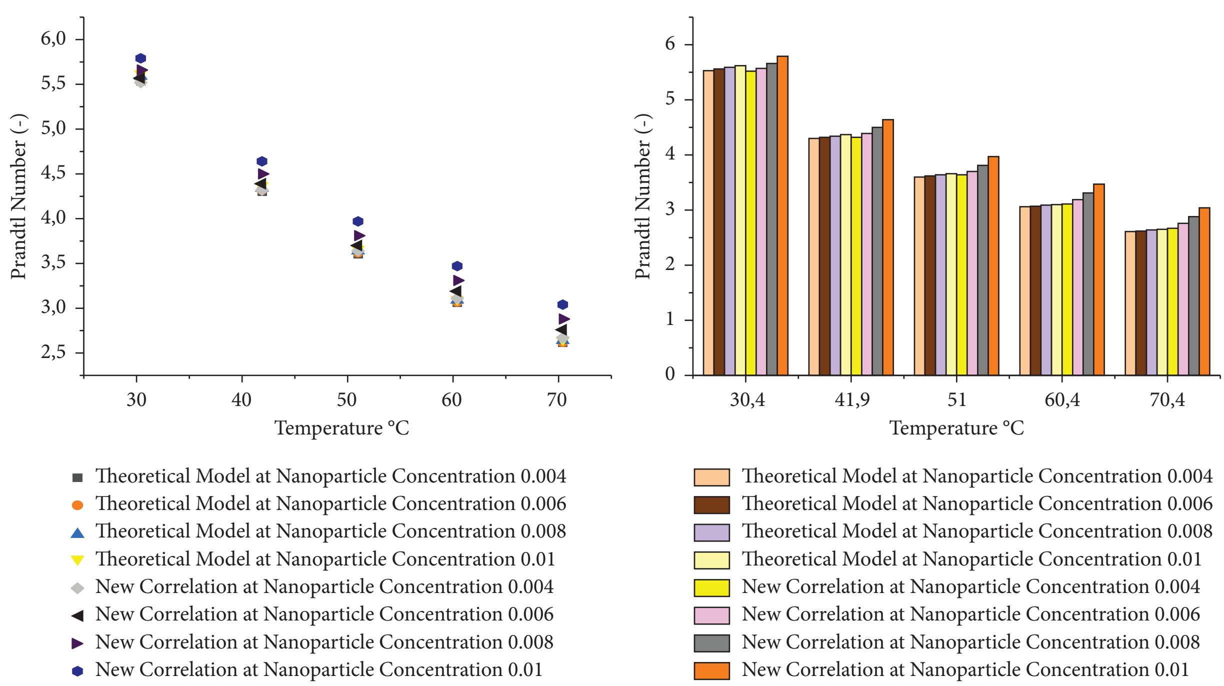

Figure 6: Comparison of titanium oxide-water nanofluid Prandtl number theoretical model and new correlation.

concentrations would affect the decrease percentage of viscosity as shown in this paper. Despite the favourable viscosity of water nanofluids, the addition of nanoparticle concentrations increases the decreasing percentage of the nanofluid relative to the base fluid, as shown in this study. This gives ethylene glycol/water combinations so much promise for usage in industrial applications that the drop in viscosity with increasing temperature for ethylene glycol (40%)/water (60%) nanofluid is identical to the fall in viscosity percentage for ethylene glycol (40%)/water (60%) base fluid. With the introduction of the new correlation for viscosity, it is confirmed that other studies have seen an increase in viscosity when nanoparticles are added and that the percentage increase in viscosity throughout the nanofluids tested is consistent. It has been demonstrated that a novel correlation as a function of temperature contributes to the research models found in the literature since it produces the desired results. With the results of the new correlation shown in Figures 1–3, we observe a decrease in viscosity, making the usage of this new correlation a viable alternative for analysing viscosity at various temperature ranges. Einstein's model does not include temperature, but with this new correlation, temperature is included, and it has been shown to produce lower viscosity rise findings when nanoparticles are introduced, making the new correlation preferable for viscosity analysis.

7. Conclusion

It is always desired that any type of fluid flows freely; therefore, in the observation of the researched study, titanium oxide-ethylene glycol (40%)/water (60%) nanofluid and titanium oxide water nanofluid had the lowest Prandtl number and were preferable to the titanium oxide ethylene glycol nanofluid. In all nanofluids observed, the highest Prandtl number and viscosity were observed at 0.01 nanoparticle concentration and 30.4 degree Celsius. Using the new correlations for Prandtl number and viscosity, this study demonstrated an increase in the Prandtl number and correlated with the previously published data. The nanofluid research study requires more precise analysis methods, which will aid in the creation of more precise designs for industrial equipment and the rescaling of existing industrial designs. The additional correlations as functions of temperature augment the literature-based research models that have demonstrated their ability to achieve the required results. With the results of the new correlations shown in Figures 1–6, we observe a decrease in viscosity and Prandtl number with an increase in temperature, making the application of the new correlations a viable alternative for analysing the viscosity at various temperature ranges. Einstein's viscosity model for nanofluid viscosity analysis does not include temperature; with this new correlation for viscosity, temperature is included, as is the case for Prandtl number. With the new correlations introduced in this study, we note that the accuracy of results remains within the same range as when using theoretical models and that the new correlations for Prandtl number and viscosity contribute to the analysis of nanofluids.

Nomenclature

P_r: Prandtl number
μ: Viscosity
k: Thermal conductivity
C_p: Specific heat
$P_{r,nf}$: Nanofluid Prandtl number
$P_{r,bf}$: Base fluid Prandtl number
μ_{bf}: Base fluid viscosity
μ_{nf}: Nanofluid viscosity
k_{bf}: Base fluid thermal conductivity
k_{nf}: Nanofluid thermal conductivity
$C_{p,p}$: Nanoparticle specific heat
$C_{p,bf}$: - Base fluid specific heat
$C_{p,nf}$: Nanofluid specific heat
ρ_p: Nanoparticle density
ρ_{bf}: Base fluid density
$\varnothing$: Nanoparticle concentration
T: Temperature
TiO_2: Titanium oxide.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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References

[1] V. Y. Rudyak, A. V. Minakov, and M. I. Pryazhnikov, "Thermal properties of nanofluids and their similarity criteria," *Technical Physics Letters*, vol. 43, no. 1, pp. 23–26, 2017.
[2] N. V. Ganesh, Q. M. Al-Mdallal, S. Al Fahel, and S. Dadoa, "Riga – plate flow of γ Al 2 O 3 -water/ethylene glycol with effective Prandtl number impacts," *Heliyon*, vol. 5, no. 5, p. 01651, 2019.
[3] J. Raza, A. M. Rohni, and Z. Omar, "MHD flow and heat transfer of Cu–water nanofluid in a semi porous channel with stretching walls," *International Journal of Heat and Mass Transfer*, vol. 103, pp. 336–340, 2016.
[4] S. Kim, H. Song, K. Yu et al., "Comparison of CFD simulations to experiment for heat transfer characteristics with aqueous Al2O3 nanofluid in heat exchanger tube," *International Communications in Heat and Mass Transfer*, vol. 95, no. 5, pp. 123–131, 2018.
[5] K. Özdemir and E. Öğüt, "Hydro-thermal behaviour determination and optimization of fully developed turbulent flow in horizontal concentric annulus with ethylene glycol and water mixture based Al2O3 nanofluids," *International Communications in Heat and Mass Transfer*, vol. 109, no. 11, Article ID 104346, 2019.
[6] Q. R. Al-Amir, S. Y. Ahmed, H. K. Hamzah, and F. H. Ali, "Effects of Prandtl number on natural convection in a cavity filled with silver/water nanofluid-saturated porous medium and non-Newtonian fluid layers separated by sinusoidal vertical interface," *Arabian Journal for Science and Engineering*, vol. 44, no. 12, pp. 10339–10354, 2019.
[7] V. Mikkola, S. Puupponen, H. Granbohm, K. Saari, T. Ala-Nissila, and A. Seppälä, "Influence of particle properties on

convective heat transfer of nanofluids," *International Journal of Thermal Sciences*, vol. 124, pp. 187–195, 2018.

[8] L. S. Sundar, H. M. Abebaw, M. K. Singh, A. M. B. Pereira, and A. C. M. Sousa, "Experimental heat transfer and friction factor of Fe3O4 magnetic nanofluids flow in a tube under laminar flow at high Prandtl numbers," *International Journal of Heat and Technology*, vol. 38, no. 2, pp. 301–313, 2020.

[9] M. Veera Krishna, "Heat transport on steady MHD flow of copper and alumina nanofluids past a stretching porous surface," *Heat Transfer*, vol. 49, no. 3, pp. 1374–1385, 2020.

[10] H. Zargartalebi, M. Ghalambaz, A. Noghrehabadi, and A. Chamkha, "Stagnation-point heat transfer of nanofluids toward stretching sheets with variable thermo-physical properties," *Advanced Powder Technology*, vol. 26, no. 3, pp. 819–829, 2015.

[11] R. Nasrin, "Applications and applied mathematics an international Prandtl number effect on assisted convective heat transfer through a solar collector Prandtl number effect on assisted convective heat transfer through a solar collector," vol. 11, no. 3, 2016.

[12] M. F. Nabil, W. H. Azmi, K. A. Hamid, and R. Mamat, "Experimental investigation of heat transfer and friction factor of TiO2-SiO2 nanofluids in water:ethylene glycol mixture," *International Journal of Heat and Mass Transfer*, vol. 124, pp. 1361–1369, 2018.

[13] L. Yu, Y. Bian, Y. Liu, and X. Xu, "Experimental investigation on rheological properties of water based nanofluids with low MWCNT concentrations," *International Journal of Heat and Mass Transfer*, vol. 135, pp. 175–185, 2019.

[14] S. N. A. Shah, S. Shahabuddin, M. F. M. Sabri et al., "Experimental investigation on stability, thermal conductivity and rheological properties of rGO/ethylene glycol based nanofluids," *International Journal of Heat and Mass Transfer*, vol. 150, Article ID 118981, 2020.

[15] S. M. Iqbal, M. Arulprakasajothi, N. D. Raja, S. M. J. Bosko, and M. B. Teja, "Investigation on the thermal behaviour of titanium dioxide nanofluid," *Materials Today Proceedings*, vol. 5, no. 9, pp. 20608–20613, 2018.

[16] S. P. Manikandan and R. Baskar, "Heat transfer studies in compact heat exchanger using zno and TiO2 nanofluids in ethylene glycol/water," *Chemical Industry and Chemical Engineering Quarterly*, vol. 24, no. 4, pp. 309–318, 2018.

[17] L. Samylingam, K. Anamalai, K. Kadirgama et al., "Thermal analysis of cellulose nanocrystal-ethylene glycol nanofluid coolant," *International Journal of Heat and Mass Transfer*, vol. 127, pp. 173–181, 2018.

[18] V. Kumar, A. K. Tiwari, and S. K. Ghosh, "Characterization and performance of nanofluids in plate heat exchanger," *Materialstoday Proceedings*, vol. 4, pp. 4070–4078, 2017.

[19] G. Żyła, J. Fal, and P. Estellé, "Thermophysical and dielectric profiles of ethylene glycol based titanium nitride (TiN–EG) nanofluids with various size of particles," *International Journal of Heat and Mass Transfer*, vol. 113, pp. 1189–1199, 2017.

[20] D. Zheng, J. Wang, Z. Chen, J. Baleta, and B. Sundén, "Performance analysis of a plate heat exchanger using various nanofluids," *International Journal of Heat and Mass Transfer*, vol. 158, Article ID 119993, 2020.

[21] Y. Tiandho, R. F. Gusa, I. Dinata, and W. Sunanda, "Model for nanofluids thermal conductivity based on modified nano-convective mechanism," *E3S Web of Conferences*, vol. 73, p. 01015, 2018.

[22] Y. B. Kho, A. Hussanan, M. K. Anuar Mohamed, and M. Z. Salleh, "Heat and mass transfer analysis on flow of Williamson nanofluid with thermal and velocity slips: buongiorno model," *Propulsion and Power Research*, vol. 8, no. 3, pp. 243–252, 2019.