

Model-Based Prediction and Comparative Analysis of Density and Specific Heat Capacity of CuO and Graphene Oxide Nanofluids in Water–Ethylene Glycol

*P Pradeepa^{1,2}, M. T. Naik¹

¹Department of Mechanical Engineering, Jawaharlal Nehru Technological University Hyderabad, University College of Engineering, Science and Technology, Hyderabad-500085, Telangana, India.

²Department of Mechanical Engineering, Government Polytechnic, Mahabubnagar, Department of Technical Education, Telangana, India.

*Corresponding Author

DOI: <https://doi.org/10.51244/IJRSI.2026.1309000032>

Received: 10 September 2026; Accepted: 21 September 2026; Published: 01 October 2026

ABSTRACT

Density and specific heat capacity are two very important thermo-physical properties used in evaluating the suitability of nanofluids for heat transfer and thermal management applications. In the present study, a model-driven comparative evaluation of copper oxide (CuO) and graphene oxide (GO) nanofluids suspended in a 60:40 by-volume water–ethylene glycol (W–EG) base fluid is proposed. The calculations were performed for the nanoparticle volume concentrations 0.05, 0.10, 0.25 and 0.50 % in the temperature range 25–55 °C. The density of W–EG base fluid was calculated from the temperature-dependent densities of water and ethylene glycol and the nanofluid density was calculated by a volume-fraction mixture relation. The specific heat capacity was calculated by a thermal-equilibrium, density-weighted mixture equation using the specific heat capacities and densities of base fluid and nanoparticles. The results show that the density decreases with increasing temperature and increases with increasing nanoparticle concentration and that the specific heat capacity increases with increasing temperature and decreases with increasing nanoparticle concentration. The density penalty of CuO is higher than that of GO because of its better density. About 2.51% and 0.38% density augmentation over base fluid at 0.5 vol% and 55 °C are predicted for CuO/W-EG and GO/W-EG respectively. For the same conditions, the calculated specific heat reduction is about 2.55% for CuO/W–EG and 0.70% for GO/W–EG. The trends are in good agreement with the experimental research carried out for GO/W–EG and CuO nanofluids, and also with the recent researches that emphasize the need for models that consider the variation of temperature and concentration. The values for current density and specific heat are theoretical and not experimental, so comparisons to the literature are to validate trends/models rather than claim a direct numerical concordance. Results show that the density penalty is lower and the base-fluid specific heat capacity is less compromised for GO/W-EG than for CuO/W-EG under the studied conditions.

Keywords: CuO nanofluid; graphene oxide; water–ethylene glycol; density; specific heat capacity; theoretical prediction; thermophysical properties; thermal management.

INTRODUCTION

The design of good heat-transfer fluids is of importance for compact heat exchangers, cooling of automobiles, thermal management in electronics, refrigeration, renewable energy systems and many other areas in which conventional coolants are limited in their effectiveness in thermal transport. Advanced working fluids such as nanofluids, which are prepared by suspending nanoscale solid particles in conventional fluids, have been extensively investigated because they can change thermal conductivity, viscosity, density, and heat capacity [1–4].

Water, ethylene glycol, and mixtures of water and ethylene glycol are the most common base fluids. The mixture of water and ethylene glycol is particularly attractive for use in cooling systems because water has a high heat capacity and ethylene glycol has antifreeze properties and a higher boiling point. Recent studies still investigate glycol/water-based and hybrid nanofluids for better thermal transfer efficiency [5, 6]. There are two kinds of nanoparticles: copper oxide (CuO) and graphene oxide (GO). CuO is a dense metal-oxide nano-particle while GO is a lightly-loaded carbonaceous two-dimensional substance. Hence, the variations of the density and effective heat capacity of the nanofluid could be very different for the same volume fractions of CuO and GO.

Density is important in that it affects mass flow rate, momentum transfer, and pumping requirements. The specific heat capacity is important because it controls the amount of thermal energy retained or transferred per unit mass for a given temperature change. Therefore, it is not possible to evaluate a nanofluid only by its thermal conductivity. The combination of density and specific heat can influence the overall thermal-management properties of a working fluid.

Direct measurement of specific heat capacity is experimentally difficult and determination of density requires appropriate equipment and temperature control. Therefore, mixture-based and empirical models are often used to estimate these properties. A 2023 study investigated the relationships between the specific heat and the density of TiO₂ nanofluids in a base fluid of 40/60 ethylene-glycol/water, comparing new temperature-dependent correlations with standard theoretical models [7]. Also, Deymi et al. [8] recently proposed density correlations based on 4004 experimental data points and showed that data-driven mathematical models can systematically improve the density forecast.

Recent studies indicate that the density-weighted thermal-equilibrium model is still an important reference point for specific heat capacity. Deymi et al. [9] investigated the main theoretical models and compared them with a large database of 2084 experimental specific-heat data points. They found that specific heat of the nanoparticles and specific heat of base fluid, nanoparticle concentration and temperature are important parameters for the prediction of specific heat. Another recent full review of 2026 also recognizes temperature and concentration as important factors influencing the specific heat capacity of nanofluids and underlines the significance of choosing models in their suitable ranges [13].

Empirical investigations provide useful validation based on trends. The experimental study of Ijam et al. [10] investigated the density and specific heat properties of GO nanosheets dispersed in a 60:40 deionized-water/ethylene-glycol mixture as a function of temperature and concentration. Khouri et al. [11] performed experimental evaluations on GO nanofluids and reported that the specific heat increased with temperature and decreased with increasing GO concentration. These observations are pertinent for the current model-oriented investigation.

The aim of this work is to perform a systematic model-based comparison of density and specific heat capacity of CuO/W–EG and GO/W–EG nanofluids at uniform temperature and concentration conditions. The analysis is consciously restricted to these two traits and separates between theoretical forecasts and empirical observations. The study also deals with the percentage change relative to the base fluid and compares the predicted trends with the literature.

Lack of Investigation and Recent Publications

The prediction of thermophysical properties is still an active area of research because the properties of nanofluids are influenced by the type and concentration of the nanoparticle, the composition of the base fluid, temperature, particle size and interfacial interactions as pointed out by recent studies. Classical mixture models are attractive as they require few inputs, but their validity depends on the physical system and accuracy of individual properties.

Table 1. Literature analysis used to validate the models and trends.

Study	Nanoparticle(s)	Base fluid	Range	Property	Relevance
Ijam A et al. (2015) [10]	GO nanosheets	DW/EG 60:40	0.01–0.10 wt%; 20–60 °C	Density, Specific heat, Thermal conductivity, viscosity	Experimental GO/W–EG data; density and Specific heat depend on nanoparticle loading and temperature
Zhou L.-P. et al. (2010) [12]	CuO	Water	Various volume fractions	Specific heat	Experimental Specific heat decreased with nanoparticle concentration; thermal-equilibrium model showed good agreement
Mlangeni P.H. et al. (2023) [7]	TiO ₂	EG/W 40:60	Low concentration; 30.4–70.4 °C	Density, Specific heat	Temperature-dependent correlations compared with theoretical models
Deymi O et al. (2023) [9]	Multiple mono-nanofluids	Multiple base fluids	2084 experimental data points	Specific heat	Developed correlations and assessed classical theoretical models
Khoury O et al. (2024) [11]	GO	DW/EG 30:70	0.01–0.10 wt%; 40–85 °C	Density, Specific heat, Thermal conductivity, Viscosity	Specific heat increased with temperature and decreased with GO concentration
Jin W et al. (2024) [6]	GO/MXene hybrid	EG/W 50:50	0–0.3 wt%; 20–60 °C	Thermal conductivity, viscosity, heat-transfer performance	Recent evidence of continued interest in glycol/water-based carbon hybrid nanofluids
Deymi et al. (2025) [8]	Multiple mono-nanofluids	Multiple base fluids	4004 experimental data points	Density	GEP/GMDH correlations; density strongly linked to nanoparticle mass concentration and base-fluid density
Present work	CuO and GO	W–EG 60:40	0.05–0.50 vol%; 25–55 °C	Density and Specific heat	Direct model-based comparison under identical conditions; theoretical results clearly separated from experimental properties

The literature shows three major deficiencies relevant to the present study. First, many experimental works are limited to either a single nanoparticle or a particular thermophysical property, thus limiting direct comparison. Second, the available correlations often have limited ranges of temperature, concentration, and base-fluid composition [7,9]. Thirdly, although GO/W–EG has been experimentally studied [10], a systematic model-based evaluation of CuO and GO in the same 60:40 W–EG base fluid under the same concentration and temperature range is rarely reported. This work investigates the above comparison by calculating the density and specific

heat capacity according to the well-known theoretical models at the constant temperature and concentration parameters.

Methodological Framework and Resources

Operational parameters and substances

The base liquid was composed of distilled water and ethylene glycol in a 60:40 volumetric ratio. CuO and GO were treated as dispersed nano-materials. The densities of the nanoparticles used in the calculations were 6300 kg m⁻³ and 1800 kg m⁻³ for CuO and GO, respectively. The calculation matrix included nanoparticle concentrations of 0.05, 0.10, 0.25 and 0.50 vol% and temperatures of 25, 30, 35, 40, 45, 50 and 55 °C.

Table 2. Thermophysical properties adopted for CuO and GO nanoparticles.

Property	Value	Source
CuO Density	6300 Kg/m ³	Literature/Manufacturer
GO Density	1800 Kg/m ³	Literature/Manufacturer
CuO Specific Heat	531 J kg ⁻¹ K ⁻¹	Literature
GO Specific Heat	700 J kg ⁻¹ K ⁻¹	Literature

The specific heat capacity for CuO (531 J kg⁻¹ K⁻¹) was in good agreement with the data reported in the nanofluid literature [12]. The specific heat value of GO at 700 J kg⁻¹ K⁻¹ is in good agreement with the available data for graphene and graphene-based materials [16].

The specific heat capacity values for CuO and GO were obtained from the existing literature as the measurement of specific heat of nanoparticle was not within the scope of this study. The selected value was used consistently in all the computations and its inclusion as an input variable is acknowledged when addressing the expected specific heat capacity of the nanofluids.

Density of base fluid

The density of the base fluid was calculated for a 60:40 volumetric blend using an additive-volume mixture formula:

$$\rho_{bf}(T) = 0.60\rho_w(T) + 0.40\rho_{EG}(T) \quad (1)$$

where $\rho_w(T)$ and $\rho_{EG}(T)$ are the temperature-dependent densities of water and ethylene glycol, respectively.

Table 3 contains the corresponding base-fluid densities.

Table 3. Density of W–EG (60:40 vol. %) base fluid as a function of temperature.

Temperature (°C)	ρ_{bf} (kg m ⁻³)
25	1044.888
30	1040.590
35	1038.018
40	1035.892
45	1031.932

50	1028.824
55	1026.768

Nanofluid Density Model

The nanofluid density was calculated by the traditional volume-fraction mixture equation:

$$\rho_{nf} = (1 - \phi)\rho_{bf} + \phi\rho_p \quad (2)$$

where ϕ is the nanoparticle volume fraction,

ρ_{bf} is the base-fluid density,

ρ_p is the nanoparticle density.

This correlation is widely used as a first order density model for sparse nanofluids. The latest density correlation studies indicate that the base fluid's density and concentration are the main parameters to predict the density of mono-nanofluids [8].

Specific heat capacity model

The specific heat capacity was calculated as a density-weighted thermal equilibrium mixture:

$$C_{p,nf} = [(1 - \phi)\rho_{bf} C_{p,bf} + \phi\rho_p C_{p,p}] / \rho_{nf} \quad (3)$$

$C_{p,nf}$: Specific heat of nanofluid.

ϕ : Volume fraction

$C_{p,bf}$: Specific heat of basefluid.

ρ_{bf} : Density of basefluid.

ρ_p : Density of nanoparticles.

$C_{p,p}$: Specific heat of nanoparticles.

ρ_{nf} : Density of nanofluid.

We choose the density-weighted thermal-equilibrium formulation that takes into account the mass contribution of the base fluid and the nanoparticles using their densities, which is more physically representative than a simple volume-fraction averaging in cases where the densities of the constituents are considerably different.

This form is identified in recent literature as the thermal-equilibrium formulation associated with Xuan and Roetzel, whereas a simpler linear volume-fraction form is commonly associated with Pak and Cho [9].

The base-fluid specific heat values used in the calculations were 3.402, 3.409, 3.419, 3.427, 3.436, 3.445 and 3.454 kJ kg⁻¹ K⁻¹ at 25–55 °C, respectively.

Table 4. Temperature-dependent specific heat capacity of the W–EG (60:40 by volume) base fluid.

Temperature (°C)	$C_{p,bf}$ (kJ kg ⁻¹ K ⁻¹)
25	3.402

30	3.409
35	3.419
40	3.427
45	3.436
50	3.445
55	3.454

Percentage changes and validation metrics

To quantify the effect of nanoparticles relative to the base fluid, density enhancement and specific-heat reduction were calculated as:

$$\text{Density change (\%)} = [(\rho_{nf} - \rho_{bf})/\rho_{bf}] \times 100 \quad (4)$$

$$\text{Specific-heat change (\%)} = [(C_{p,nf} - C_{p,bf})/C_{p,bf}] \times 100 \quad (5)$$

No experimental uncertainty or experimental AAPRE/RMSE is assigned to the calculated values as no direct measurements of density and specific heat were done in the present work. Instead, validation is done at the model-form/trend level by independent published studies. If the base-fluid ratios, units of concentration or the temperature ranges of published studies are different, they are used only for qualitative validation and not for direct numerical validation.

Model Applicability and Validation Approach

In this study, the mixture relations were used to predict the density and the specific heat capacity of CuO and GO nanofluids in the temperature range of 25–55 °C and nanoparticle volume concentration of 0.05–0.5 vol.%. The relations of density and specific heat capacity are equilibrium mixture equations which take into account the effect of base fluid and nanoparticles through their volume fractions, densities and specific heat capacities.

These relationships are mixture-oriented predictive frameworks appropriate for estimating overall thermophysical properties from constituent phase properties. They are not intended to describe complex microscale phenomena such as particle–particle interactions, nanoparticle aggregation, Brownian motion or interfacial effects. Hence, the present study focuses on the determination of the macroscopic thermophysical properties of the investigated nanofluids.

The selected concentration range is relatively low nanoparticle suspensions, so that the nanofluid can be considered as a uniform mixture for bulk property evaluation. However, the predicted values are dependent on the accuracy of the input parameters, particularly the density and the specific heat capacity of the nanoparticles. Therefore, the results are mainly discussed in terms of the expected variation and trends relative to temperature and nanoparticle concentration. Experimental verification of the values predicted is required to be quantitative for the case of uniform temperature and concentration.

RESULTS AND DISCUSSION

Density

Table 5 summarizes the predicted density values. For both nanofluids, the density decreases as temperature goes up and increases as nanoparticle concentration goes up. The decrease of density by an increase of temperature is mainly due to the thermal expansion of the base fluid. As the temperature increases, the volume of the liquid phase increases and the density decreases.

The behavior is directly attributed to Eq. (2) because the density of the base fluid decreases with temperature, whereas the density of the nanoparticle is considered to be constant over the temperature range examined. The anticipated density rose as nanoparticle concentration augmented, as the incorporation of solid nanoparticles substitutes a segment of the lower-density base fluid with a more substantial solid phase. Given that the density of CuO significantly surpasses that of the W–EG base fluid, the enhancement becomes more evident with a rising nanoparticle volume fraction.

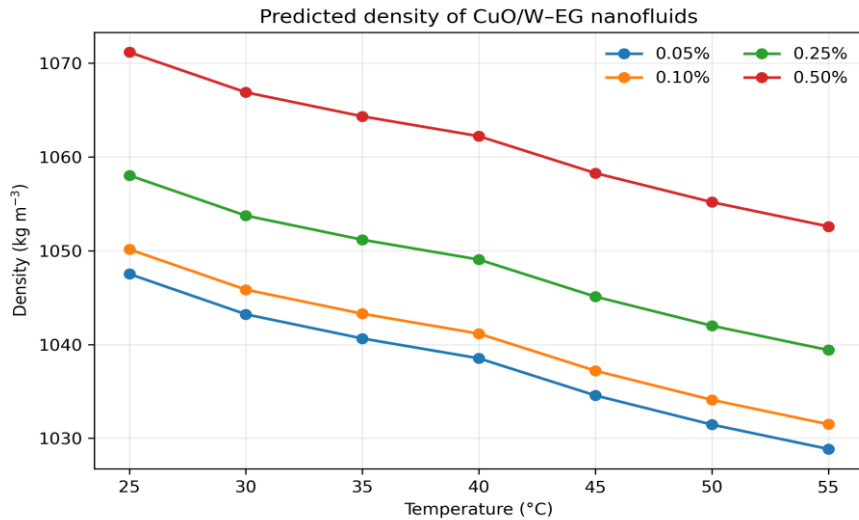


Figure 1. Density of CuO/W–EG nanofluids at different concentrations.

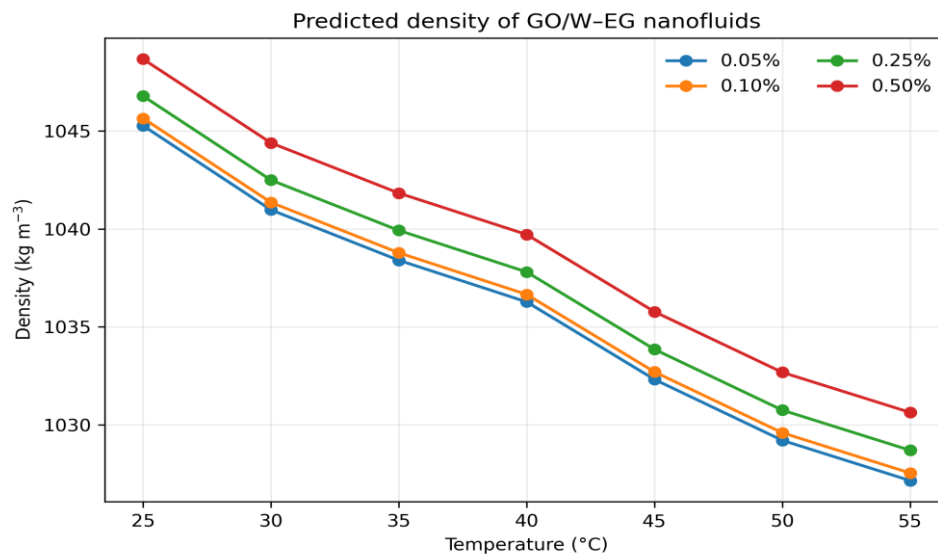


Figure 2. Density of GO/W–EG nanofluids at different concentrations.

Table 5. Density of CuO/W–EG and GO/W–EG nanofluids at different temperatures and concentrations.

T (°C)	CuO 0.05%	CuO 0.10%	CuO 0.25%	CuO 0.50%	GO 0.05%	GO 0.10%	GO 0.25%	GO 0.50%
25	1047.515	1050.143	1058.025	1071.163	1045.265	1045.643	1046.775	1048.663
30	1043.219	1045.849	1053.738	1066.887	1040.969	1041.349	1042.488	1044.387
35	1040.640	1043.279	1051.172	1064.327	1038.398	1038.779	1039.922	1041.827

40	1038.524	1041.156	1049.052	1062.212	1036.274	1036.656	1037.802	1039.712
45	1034.566	1037.200	1045.102	1058.272	1032.316	1032.700	1033.852	1035.772
50	1031.459	1034.095	1042.001	1055.179	1029.209	1029.595	1030.751	1032.679
55	1028.856	1031.493	1039.404	1052.588	1027.154	1027.541	1028.701	1030.634

The density of 0.5 vol% CuO/W–EG at 25 °C is approximately 1071.16 kg m^{−3}, which is higher than the base fluid, 1044.89 kg m^{−3}. The corresponding values at 55 °C are 1052.59 kg m^{−3} and 1026.77 kg m^{−3}. The density of GO is 1048.66 kg m^{−3} at 0.5 vol% at 25 °C and 1030.63 kg m^{−3} at 55 °C. The much lower density increase produced by GO is directly related to the lower assumed density for GO.

This general trend is supported by recent experimental and modeling studies. Mlangeni et al. [7] reported that the density increases with addition of nanoparticles and decreases with temperature in glycol/water based nanofluids. The most influential parameters that control the density of nanofluid are nanoparticle mass concentration and base-fluid density as found by Deymi et al. [8]. The direction of the predictions of the present model is thus consistent with independent literature.

Density enhancement relative to the base fluid

Table 6. Density enhancement relative to the W–EG base fluid.

T (°C)	CuO 0.05%	CuO 0.10%	CuO 0.25%	CuO 0.50%	GO 0.05%	GO 0.10%	GO 0.25%	GO 0.50%
25	0.251	0.503	1.257	2.515	0.036	0.072	0.181	0.361
55	0.203	0.460	1.231	2.515	0.038	0.075	0.188	0.377

At 0.5 vol% and 55 °C, the predicted density enhancement is around 2.51% and 0.38% for CuO/W–EG and GO/W–EG respectively. The difference is large enough to be significant for the calculation of the mass-based and hydraulic characteristics of cooling loops. A lower density means less strain on pumps and fluid-handling equipment, all while ensuring better heat-transfer performance.

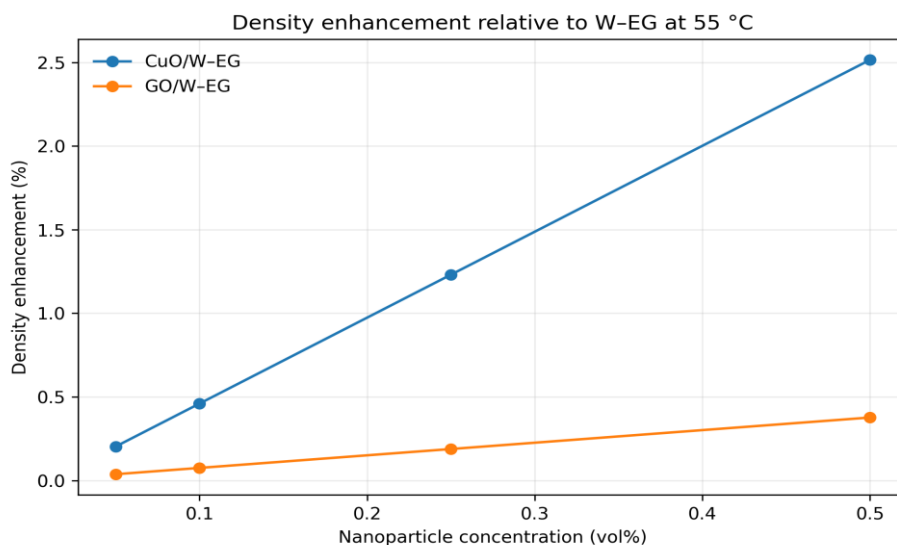


Figure 3. Density enhancement relative to the W–EG base fluid at 55 °C.

The density variation with temperature and nanoparticle concentration is expected to follow the trends reported in previous studies. The decrease in density with temperature and increase in density with concentration of nanoparticle are in agreement with the expected behavior of nanofluid mixtures and results reported in literature. This comparison is a trend verification, not a direct numerical verification, because the present study uses mixture-model forecasts.

Specific heat capacity

Table 7. Specific heat capacity of CuO/W–EG and GO/W–EG nanofluids at different temperatures and concentrations.

T (°C)	CuO 0.05%	CuO 0.10%	CuO 0.25%	CuO 0.50%	GO 0.05%	GO 0.10%	GO 0.25%	GO 0.50%
25	3.393	3.384	3.359	3.317	3.399	3.397	3.390	3.379
30	3.400	3.391	3.365	3.324	3.406	3.404	3.397	3.386
35	3.410	3.401	3.375	3.336	3.416	3.414	3.407	3.395
40	3.418	3.409	3.383	3.341	3.424	3.422	3.415	3.403
45	3.427	3.418	3.392	3.349	3.433	3.431	3.424	3.412
50	3.436	3.427	3.400	3.358	3.442	3.440	3.433	3.421
55	3.445	3.436	3.409	3.366	3.451	3.449	3.442	3.430

The predicted specific heat capacity increases with temperature for both the nanofluids and decreases with increasing the nanoparticle concentration. The base-fluid value at 55 °C is 3.454 kJ kg^{−1} K^{−1} while the predicted values at 0.5 vol% are 3.366 kJ kg^{−1} K^{−1} for CuO/W–EG and 3.430 kJ kg^{−1} K^{−1} for GO/W–EG.

The variation of specific heat capacity with temperature is mainly due to the temperature dependence of the thermophysical properties of the W–EG base fluid used in the calculation. Due to the low concentration of nanoparticles, the specific heat capacity of the base fluid controls the total specific heat capacity of the nanofluid. Thus, the expected temperature-dependent variation of the nanofluid specific heat is consistent with the respective variation of the base fluid specific heat, whereas the nanoparticles determine the extent of the predicted value according to their density and specific heat capacity.

The addition of nanoparticles changed the mass ratio of the base fluid and solid phase in the composite, therefore, the expected specific heat capacity of nanofluids changed with the increase of the nanoparticle concentration. The density-weighted thermal-equilibrium model employed in this study gives a specific heat capacity which depends on the densities and specific heat capacities of the two components. Therefore, the change in the nanofluid specific heat in both direction and magnitude is controlled by the specific heat capacity and density of the nanoparticles relative to the W–EG base fluid. The total specific heat capacity is mainly determined by the base fluid at the low nanoparticle concentrations investigated.

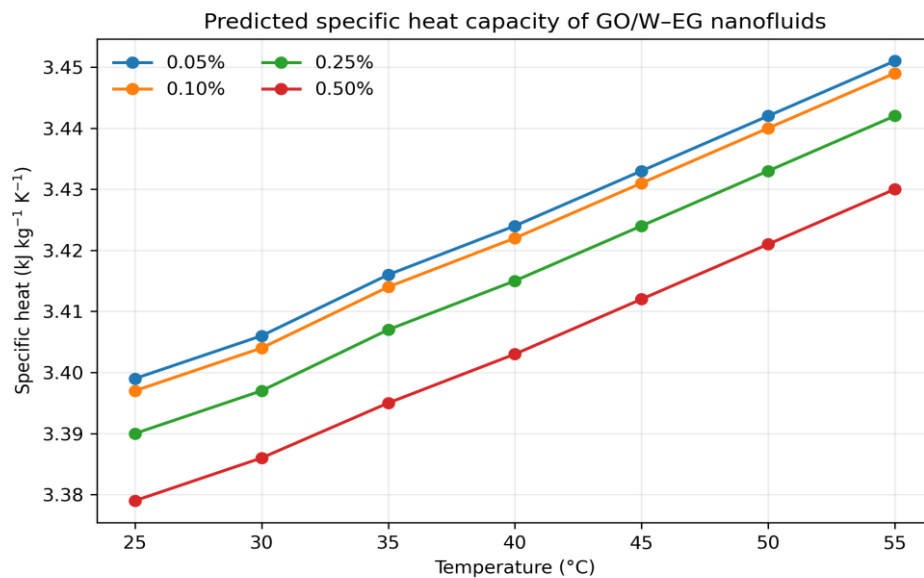


Figure 4. Specific heat capacity of CuO/W–EG nanofluids at different concentrations.

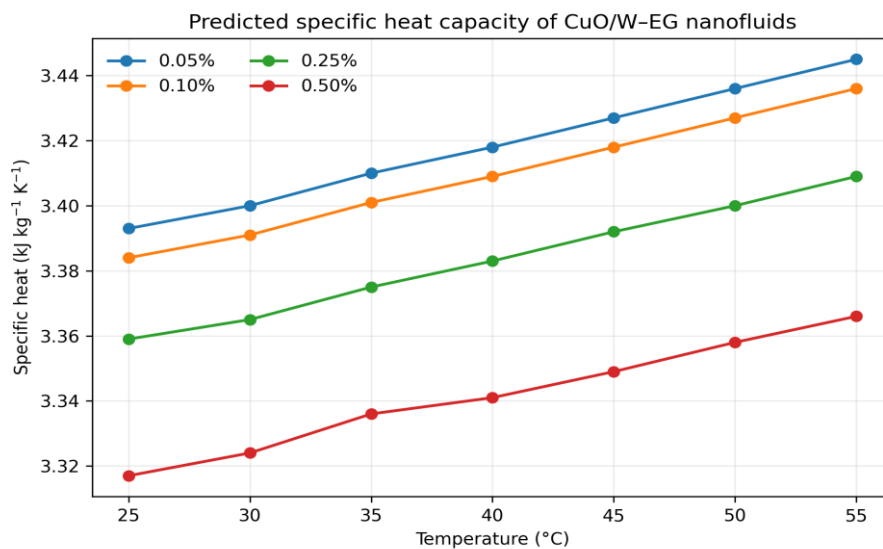


Figure 5. Specific heat capacity of GO/W–EG nanofluids at different concentrations.

The higher reduction of specific heat for CuO nanofluid is due to its lower specific heat than the base fluid W–EG and the density weighted contribution of the particles in Eq. (3). Zhou et al. [12] experimentally reported the specific heat of CuO nanofluid decreases with particle volume fraction and found good agreement between measurements and the thermal-equilibrium model. This gives important model-form support for the present CuO calculations.

Decrease in specific heat relative to the base fluid

Table 8. Specific-heat change relative to the W–EG base fluid.

T (°C)	CuO 0.05%	CuO 0.10%	CuO 0.25%	CuO 0.50%	GO 0.05%	GO 0.10%	GO 0.25%	GO 0.50%
25	-0.265	-0.529	-1.264	-2.499	-0.088	-0.147	-0.353	-0.676
55	-0.261	-0.521	-1.303	-2.548	-0.087	-0.145	-0.347	-0.695

The calculated reduction in specific heat at 0.5 vol% and 55 °C is approximately 2.55% for CuO/W–EG and 0.70% for GO/W–EG. Therefore, under the present model, GO retains a larger fraction of the base fluid heat-storage capacity owing to the layered structure and composition of GO

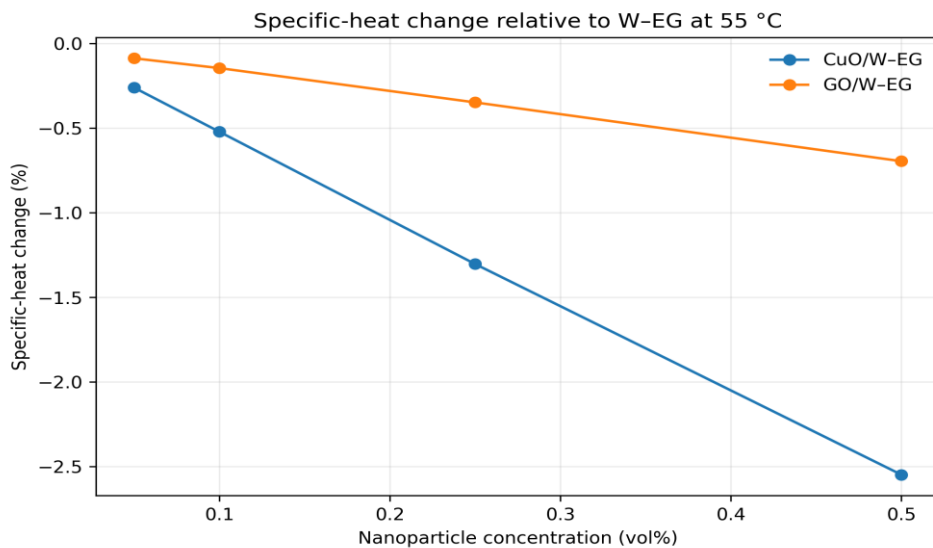


Figure 6. Specific-heat change relative to the W–EG base fluid at 55 °C.

The expected change in specific heat capacity with temperature and nanoparticle volume fraction agrees with the trends reported in the literature. The observed variation is due to the relative effects of W–EG base fluid and nanoparticles on the density-weighted thermal equilibrium model. The comparison allows for the confirmation of expected trends but does not constitute a direct numerical validation, as no experimental measurements are available under the same conditions in this study.

Influence of Temperature

Temperature has opposite effects on the two properties targeted. Density is inversely proportional to temperature. Specific heat capacity is proportional to temperature. The density behavior follows the temperature dependence of water and ethylene glycol and the specific-heat behavior follows the specific heat of the base fluid used in Eq. (3) with temperature dependence. The obtained trends are in agreement with recent experimental works on GO nanofluids. Khouri et al. [11] reported that specific heat increased with temperature and decreased with increasing GO concentration. The comparison is intentionally trend based and not numerical as in their study they used a 30:70 water/ethylene-glycol mixture rather than the 60:40 mixture used in the present work.

The effect of nanoparticle concentration

Density increases with increasing nanoparticle concentration because of a larger fraction of the suspension being occupied by the solid phase. The effect is much larger for CuO than for GO because 6300 kg m^{-3} is much larger than 1800 kg m^{-3} . In contrast, the specific heat decreases with increasing concentration due to the heat capacities of the selected nanoparticles being lower than that of the W–EG base fluid. The effect is larger for CuO again. This concentration dependence is consistent with the general behavior reported by Zhou et al. [12], Ijam et al. [10] and Khouri et al. [11].

Limitations and Scope of the Model

One limitation of this study is that not all expected properties were directly experimentally tested. Therefore the present results have to be seen as predictions of the model. Experimental measurements at uniform temperature and concentration are needed for quantitative validation of the predicted values. Further experimental studies under uniform conditions will permit quantitative confirmation and will increase the relevance of the selected mixture relations.

Validation of the Model Predictions through Literature

As density and specific heat capacity were not measured directly in this study, validation is carried out in two stages: (i) validation of the mathematical form against established literature models, and (ii) validation of predicted trends against independent experimental studies. For cases in which the published study uses a different base-fluid ratio, concentration basis, or nanoparticle material, no direct percentage error is claimed against the published experimental values.

Table 9. Summary of literature-based validation of the present model predictions.

Validation aspect	Reference	System	Reported evidence	Relevance to present work
Specific heat model	Zhou L.-P. et al. (2010) [12]	CuO nanofluid	Thermal-equilibrium model was in good agreement with experiment	Supports density-weighted thermal equilibrium form for CuO
Specific heat trend	Ijam A et al. (2015) [10]	GO in DW/EG 60:40	Specific heat and density varied with nanoparticle concentration and temperature	Supports temperature and concentration dependence
Specific heat trend	Khoury O et al. (2024) [11]	GO nanofluid, DW/EG 30:70	Specific heat increases with Temperature and decreases with GO concentration	Matches present GO trend
Modeling framework	Deymi O et al. (2023) [9]	Multiple mono-nanofluids	Classical Specific heat models compared with 2084 experimental points	Supports model-based Specific heat analysis and need for range awareness
Density trend/modeling	Mlangeni P.H. et al. (2023) [7]	TiO ₂ in EG/W 40:60	Density and Specific heat correlations compared with theoretical models	Supports temperature-dependent modeling in glycol/water fluids
Density modeling	Deymi O et al. (2025) [8]	4004 experimental points	GEP/GMDH density correlations; concentration and base-fluid density important	Supports concentration/base-fluid dependence of density

The present predictions are found to reproduce the direction of change reported independently for density and specific heat, in the validation. More importantly, the CuO specific-heat formulation is validated by precedent in experimental/model comparisons [12]. Recent work with large databases point out that specific heat and density are highly system dependent and that correlations should not be used outside their validated ranges without caution [8,9].

One useful approach for future validation would be to measure the density using a temperature-controlled density meter or pycnometer and the specific heat using differential scanning calorimetry or an appropriate calorimetric system. Such measurements would allow computation of AAPRE, RMSE and R² in relation to the present model predictions.

Engineering Considerations

The combined density and specific-heat data indicates that GO/W–EG has a better property balance than CuO/W–EG under the model conditions considered. The lower increase in density results in a smaller mass-density penalty, and the smaller decrease in specific heat results in a better retention of the heat-storage capacity of the base fluid. But these benefits need to be weighed against thermal conductivity, viscosity, stability and

actual heat transfer performance. Therefore, the present study does not claim that GO is always better, but it does point out a favorable density–specific-heat combination in the range studied.

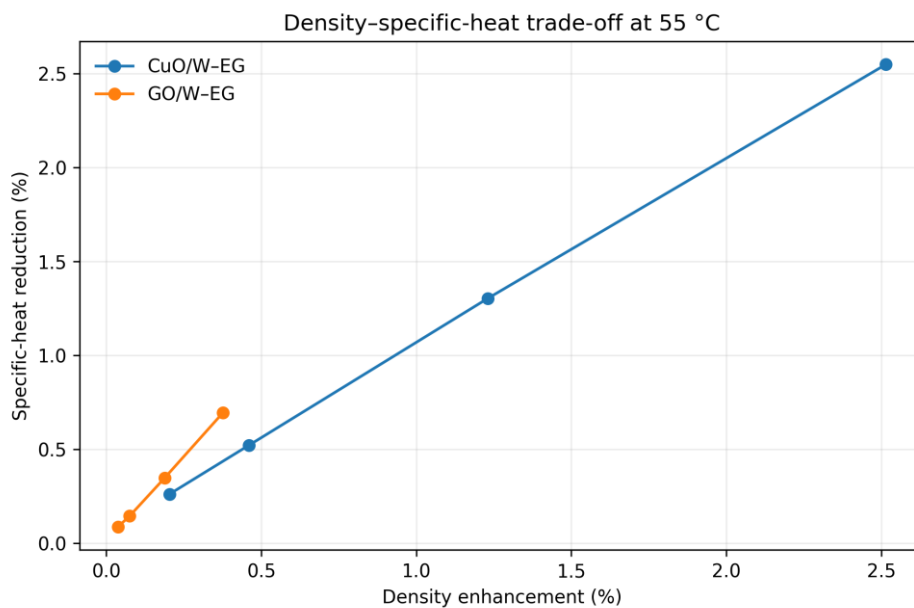


Figure 7. Density enhancement versus specific-heat reduction at 55 °C.

CONCLUSIONS

1. The density and specific heat capacity of CuO/W–EG and GO/W–EG were calculated using the well-known mixture relations and thermal equilibrium relations in the temperature range 25–55 °C and nanoparticle concentration of 0.05–0.50 vol%.
2. Both nanofluids' density decreases with temperature and increases with nanoparticle concentration.
3. CuO nanofluid produces a substantially larger density increase than GO nanofluid because the assumed CuO density (6300 kg m⁻³) is much greater than that of GO (1800 kg m⁻³).
4. The predicted density enhancement relative to base fluid is approximately 2.51% and 0.38% for CuO/W–EG and GO/W–EG, respectively, at 0.5 vol% and 55 °C.
5. Specific heat capacity is found to increase with temperature and decrease with nanoparticle concentration for both nanofluids.
6. The predicted decrease in specific-heat at 0.5 vol% and 55 °C is about 2.55% for CuO/W–EG and 0.70% for GO/W–EG.
7. The trends predicted are consistent with independent experimental and modeling literature, including published studies on CuO nanofluids, GO/W–EG nanofluids and glycol/water-based nanofluids.
8. GO/W–EG has a lower density penalty and retains specific heat capacity better than CuO/W–EG under the current model assumptions.
9. Future work should measure density and specific heat experimentally under identical conditions so as to validate the model quantitatively and to determine property-specific uncertainty.

Declarations

No external funding was received for this research.

REFERENCES

1. Choi S.U.S., Eastman J.A. (1995). Enhancing thermal conductivity of fluids with nanoparticles. ASME International Mechanical Engineering Congress and Exposition, 99–105.
2. Said, Z., L Syam Sundar, Arun Kumar Tiwari, Hafiz Muhammad Ali, Mohsen Sheikholeslami, Evagleos Bellos, Hamza Babar (2022). Recent advances on the fundamental physical phenomena behind stability, dynamic motion, thermophysical properties, heat transport, applications, and challenges of nanofluids. *Physics Reports*, 946, 1–94. <https://doi.org/10.1016/j.physrep.2021.07.002>
3. Le Ba, T., Mahian, O., Wongwises, S. *et al.* (2020). Review on the recent progress in the preparation and stability of graphene-based nanofluids. *Journal of Thermal Analysis and Calorimetry*, 142, 1145–1172. <https://doi.org/10.1007/s10973-020-09365-9>
4. Lin Qiu, Ning Zhu, Yanhui Feng, Xinxin Zhang *et al.* (2020). A review of recent advances in thermophysical properties at the nanoscale: From solid state to colloids. *Physics Reports*, 843, 1–81. <https://doi.org/10.1016/j.physrep.2019.12.001>
5. Rashidi, O., Sajadi, S.M., Soufivand, M. *et al.* (2024). Experimental study to improve the hydrodynamic and thermal efficiencies of a cross-flow car radiator using a new prepared hybrid nanofluid composed of graphene oxide and silicon oxide nanoparticles dispersed in water–ethylene glycol fluid. *International Journal of Thermophysics*, 45, 23. <https://doi.org/10.1007/s10765-023-03310-2>
6. Jin W, Jiang L, Lv Y, Li K, Liu H, Cao W, Chen C, Chen Z, Li W (2024). Experimental study on preparation and heat transfer efficiency of ethylene glycol/water-based hybrid nanofluids enhanced by graphene oxide/MXene nanoparticles. *Journal of Molecular Liquids*, 405, 125033. <https://doi.org/10.1016/j.molliq.2024.125033>
7. Mlangeni P.H., Huan Z, Sithebe T, Veeredhi V.R. (2023). Correlations for specific heat and density of Titanium Oxide Nanofluid at low nanoparticle concentrations. *Materials Today: Proceedings*, 92 (2), 1175–1181. <https://doi.org/10.1016/j.matpr.2023.05.238>
8. Deymi O, Hadavimoghaddam F, Atashrouz S, Kar S, Abedi A, Mohaddespour A, Ostadhassan M, Hemmati-Sarapardeh A (2025). Innovative mathematical correlations for estimating mono-nanofluids' density: Insights from white-box machine learning. *Results in Physics*, 73, 108248. <https://doi.org/10.1016/j.rinp.2025.108248>
9. Deymi O, Hadavimoghaddam F, Atashrouz S, Nedeljkovic D, Abuswer M.A, Hemmati-Sarapardeh A, Mohaddespour A (2023). Toward empirical correlations for estimating the specific heat capacity of nanofluids utilizing GRG, GP, GEP, and GMDH. *Scientific Reports*, 13, 20763. <https://doi.org/10.1038/s41598-023-47327-x>
10. Ijam A, Saidur R, Ganesan P, Moradi Golsheikh A (2015). Stability, thermo-physical properties, and electrical conductivity of graphene oxide-deionized water/ethylene glycol based nanofluid. *International Journal of Heat and Mass Transfer*, 87, 92–103. <https://doi.org/10.1016/j.ijheatmasstransfer.2015.02.060>
11. Khouri O, Goshayeshi H.R., Mousavi S.B., Hosseini Nami S, Zeinali Heris S (2024). Heat Transfer Enhancement in Industrial Heat Exchangers Using Graphene Oxide Nanofluids. *ACS Omega*, 9(22), 24025–24038. <https://doi.org/10.1021/acsomega.4c02581>
12. Zhou L.-P., Wang B.-X., Peng X.-F., Du X.-Z., Yang Y.-P. (2010). On the Specific Heat Capacity of CuO Nanofluid. *Advances in Mechanical Engineering*, 2010, 172085. <https://doi.org/10.1155/2010/172085>
13. Zhong H, Yang L, Song J, Wu X, Li X (2026). Recent Progress in Nanofluid Specific Heat Capacity: A Comprehensive Review. *Journal of Thermal Science*, 35, 256–283. <https://doi.org/10.1007/s11630-025-2164-8>
14. Gałek R, Wilk J (2024). Investigations of the specific heat capacity of selected heterogeneous materials. *Archives of Thermodynamics*, 45(2), 91–98. <https://doi.org/10.24425/ather.2024.150855>