

Density and Specific Heat Capacity of 50:50 by Volume CuO–GO Hybrid Nanofluids in Water–Ethylene Glycol (60:40)

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ABSTRACT

The present study evaluates the density and specific heat capacity of a CuO–GO hybrid nanofluid dispersed in a water–ethylene glycol (W–EG) mixture with a 60:40 volume ratio. The CuO and GO nanoparticles were incorporated at a 50:50 ratio by volume. CuO nanoparticles with a density of 6300 kg m^{-3} and graphene oxide (GO) nanoparticles with a density of 1800 kg m^{-3} were considered. The total hybrid nanoparticle concentrations were 0.05, 0.10, 0.25 and 0.50 vol.%, and calculations were performed over a temperature range of 25–55 °C. The density of the hybrid nanofluid was determined using a mixture-based relation, while specific heat capacity was calculated using a density-weighted thermal-equilibrium relation. For a 50:50-by-volume CuO–GO mixture, the effective density was calculated as 4050 kg m^{-3} , while the effective specific heat capacity was $0.5686 \text{ kJ kg}^{-1} \text{ K}^{-1}$ based on the constituent properties used in the present analysis. The predicted density decreased with increasing temperature and increased with increasing nanoparticle concentration. Conversely, specific heat capacity increased with temperature and decreased with nanoparticle concentration. At 0.50 vol.% and 55 °C, the predicted density was $1041.88 \text{ kg m}^{-3}$, corresponding to an increase of approximately 1.47% relative to the base fluid, whereas the predicted specific heat capacity was $3.3979 \text{ kJ kg}^{-1} \text{ K}^{-1}$, corresponding to a reduction of approximately 1.62%. The results provide model-based information regarding the influence of temperature and hybrid nanoparticle concentration on the density and energy-storage characteristics of CuO–GO/W–EG hybrid nanofluids.

Keywords: CuO–GO hybrid nanofluid; water–ethylene glycol; density; specific heat capacity; 50:50 volume ratio; thermophysical properties; thermal management.

SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology (2026);

DOI: 10.18090/samriddhi.v18i03.06

INTRODUCTION

The increasing demand for compact and efficient thermal-management systems has stimulated extensive research into advanced heat-transfer fluids. Conventional fluids such as water, ethylene glycol and their mixtures are widely used in thermal systems because of their favourable availability, stability and operating characteristics. However, their relatively limited thermal transport capability has encouraged researchers to develop engineered fluids with improved thermophysical properties.

Nanofluids are suspensions of nanoparticles in conventional base fluids and have been extensively investigated for heat-transfer applications. The addition of nanoparticles can alter thermal conductivity, viscosity, density, specific heat capacity and other transport characteristics. The magnitude and direction of these changes depend on nanoparticle material, concentration, particle size, temperature, base-fluid composition and dispersion quality.

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How to cite this article: Pradeepa, P., Naik, M.T. (2026). Density and Specific Heat Capacity of 50:50 by Volume CuO–GO Hybrid Nanofluids in Water–Ethylene Glycol (60:40). *SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology*, 18(3), 96-102.

Source of support: Nil

Conflict of interest: None

Hybrid nanofluids represent a further development in nanofluid technology in which two or more different nanoparticles are simultaneously dispersed in a base fluid. The use of two nanoparticle materials provides an opportunity to combine their individual characteristics and tailor the resulting thermophysical behaviour. Previous

investigations have demonstrated that hybrid nanofluids can exhibit improved thermal properties, although the enhancement is strongly dependent on nanoparticle composition and mixing ratio.

Copper oxide (CuO) is a metal-oxide nanoparticle with relatively high density and useful thermal properties, whereas graphene oxide (GO) is a carbon-based nanomaterial characterized by a large surface area and oxygen-containing functional groups. The combination of CuO and GO is therefore of interest for thermal-management applications. Previous investigations have reported CuO–GO systems in water and other base fluids, while comparatively less information is available for CuO–GO hybrid nanofluids dispersed in water–ethylene glycol mixtures.

Water–ethylene glycol mixtures are particularly important because they are widely used in automotive cooling systems, heat exchangers, electronic cooling and other thermal applications. The 60:40 water–ethylene glycol mixture provides a useful combination of thermal and antifreeze characteristics.

The hybrid nanofluids considered in this study contain total nanoparticle concentrations of 0.05, 0.10, 0.25 and 0.50 vol.% and were evaluated over 25–55 °C. Density and specific heat capacity were determined using mixture-based relations, while the associated thermal transport and rheological properties are treated separately in the experimental study.

The hybrid composition was defined on a volume basis. Because CuO and GO have substantially different densities, equal constituent volumes correspond to unequal constituent masses.

Accordingly, CuO:GO = 50:50 by volume was maintained throughout the formulation and calculations, providing a consistent basis for determining the effective hybrid-particle properties.

The objective of this study is to evaluate the influence of temperature and total hybrid nanoparticle volume concentration on the predicted density and specific heat capacity of CuO–GO/W–EG hybrid nanofluids. The study specifically considers CuO:GO = 50:50 by volume and focuses on calculated thermophysical properties, thereby providing a consistent formulation basis for comparison and future experimental validation.

Recent literature further demonstrates the growing interest in hybrid nanofluids and the need to evaluate their thermophysical behaviour under clearly defined formulation and operating conditions. Kanti et al. investigated CuO–GO hybrid nanofluids at different mixing ratios and reported that the 50:50 GO/CuO hybrid formulation exhibited higher thermal conductivity and viscosity than a 20:80 formulation over 0.1–1.0 vol.% and 30–60 °C. Their work also showed that pH, surfactant selection and dispersion stability can substantially influence the measured properties [9].

Shaik et al. reported the thermophysical characterization of water-based Cu–graphene hybrid nanofluids and

demonstrated the importance of hybrid composition, concentration and stability in determining thermal and rheological performance. The study also calculated specific heat and pumping power, emphasizing that thermal enhancement should be considered together with flow-related penalties [10].

More recent reviews have emphasized that the thermophysical response of hybrid nanofluids depends on nanoparticle composition, mixing ratio, concentration, temperature, particle characteristics, preparation procedure and dispersion stability. Singh and Sood reviewed density, specific heat, viscosity and thermal conductivity as key properties for hybrid nanofluids and highlighted the importance of formulation optimization [11]. Das et al. similarly identified preparation, stabilization and characterization as major factors governing the reproducibility and practical application of hybrid nanofluids [12].

The current literature also points toward a continuing need for reliable formulation-specific data. A 2025 critical review identified stability and thermal conductivity as closely coupled issues and emphasized the effects of nanoparticle type, volume fraction, surfactant, surface functionalization and ultrasonication on hybrid nanofluid behaviour [13]. Kalsi et al. further reviewed recent advances, synthesis methods, applications and challenges of hybrid nanofluids, noting that performance variability under different working conditions remains an important research issue [14].

Importantly, a recent experimental study published in Powder Technology investigated a GO–CuO/water hybrid nanofluid containing 20% GO and 80% CuO by volume at 0.15–0.75 vol.% and 25–50 °C. The study reported increasing thermal conductivity with both temperature and concentration and proposed a high-accuracy correlation for the measured data [15]. A 2026 review has further emphasized that hybrid-nanofluid performance is controlled by the combined effects of nanoparticle composition, base fluid, mixing ratio, concentration, temperature, sonication and stability, and that thermal enhancement must be balanced against viscosity, pumping power and practical stability [16].

Although these studies establish the importance of CuO–GO hybridization, the available literature is dominated by water-based systems and by investigations of thermal conductivity, viscosity, stability or convective heat transfer. There is comparatively limited formulation-specific information on the density and specific heat capacity of CuO–GO hybrid nanofluids dispersed in a 60:40 water–ethylene glycol base fluid, particularly when the CuO:GO composition is explicitly maintained at 50:50 by volume. The present study addresses this gap by systematically evaluating the calculated density and specific heat capacity over 25–55 °C and total hybrid nanoparticle concentrations of 0.05–0.50 vol.%.

MATERIALS AND METHODOLOGY

Base Fluid

The base fluid consisted of distilled water and ethylene glycol mixed in a 60:40 volume ratio. The density of the base fluid was calculated at temperatures between 25 and 55 °C using the densities of water and ethylene glycol. The resulting W–EG base-fluid density varied from 1044.888 kg m⁻³ at 25 °C to 1026.768 kg m⁻³ at 55 °C. The corresponding base-fluid specific heat capacity increased from 3.402 kJ kg⁻¹ K⁻¹ at 25 °C to 3.454 kJ kg⁻¹ K⁻¹ at 55 °C.

Nanoparticles

Commercially available CuO nanoparticles and graphene oxide were considered for the hybrid nanofluid formulation. The nanoparticle properties used in the calculations were: CuO density = 6300 kg m⁻³; GO density = 1800 kg m⁻³; CuO specific heat = 0.531 kJ kg⁻¹ K⁻¹; and GO specific heat = 0.700 kJ kg⁻¹ K⁻¹.

Hybrid Composition: CuO:GO = 50:50 by Volume

In the present study, the CuO and GO nanoparticles are considered in an equal-volume ratio:

$$VCuO : VGO = 50 : 50$$

Therefore, $\phi_{CuO} = \phi/2$ and $\phi_{GO} = \phi/2$, where ϕ is the total volume fraction of hybrid nanoparticles. Thus, for a total hybrid concentration of 0.50 vol.%, $\phi_{CuO} = 0.25\%$ and $\phi_{GO} = 0.25\%$. This definition is used consistently for all concentrations.

Calculation of Nanoparticle Mass for 50:50 Volume Ratio

The total nanoparticle volume fraction is defined as:

$$\phi = V_{np} / (V_{np} + V_{bf})$$

Table 1: Thermophysical properties of the W–EG (60:40) base fluid

Temperature (°C)	Density (kg m ⁻³)	Specific heat (kJ kg ⁻¹ K ⁻¹)
25	1044.888	3.402
30	1040.590	3.409
35	1038.018	3.419
40	1035.892	3.427
45	1031.932	3.436
50	1028.824	3.445
55	1026.768	3.454

Therefore:

$$V_{np} = [\phi/(1 - \phi)] V_{bf}$$

For 100 mL of base fluid, $V_{bf} = 100$ mL. For 0.05 vol.%:

$$V_{np} = [0.0005/(1 - 0.0005)](100) = 0.050025 \text{ mL}$$

Since the CuO:GO ratio is 50:50 by volume:

$$VCuO = VGO = 0.0250125 \text{ mL}$$

The corresponding masses are:

$$m_{CuO} = VCuO \rho_{CuO} = 0.15758 \text{ g}$$

$$m_{GO} = VGO \rho_{GO} = 0.04502 \text{ g}$$

Thus, although the volume ratio is 50:50, the mass ratio is approximately 3.5:1.

Effective Density of the 50:50-by-Volume Hybrid Solid

For equal volumes of CuO and GO, the effective density is:

$$\rho_{p,eff} = [\rho_{CuO} VCuO + \rho_{GO} VGO] / [VCuO + VGO]$$

Since $VCuO = VGO$:

$$\rho_{p,eff} = (\rho_{CuO} + \rho_{GO})/2 = (6300 + 1800)/2$$

$$\rho_{p,eff} = 4050 \text{ kg m}^{-3}$$

Effective Specific Heat of the Hybrid Solid

The effective specific heat is obtained by considering the volumetric heat-capacity contributions:

$$C_{p,p,eff} = [\rho_{CuO} VCuO C_{p,CuO} + \rho_{GO} VGO C_{p,GO}] / [\rho_{CuO} VCuO + \rho_{GO} VGO]$$

For equal constituent volumes:

$$C_{p,p,eff} = [\rho_{CuO} C_{p,CuO} + \rho_{GO} C_{p,GO}] / [\rho_{CuO} + \rho_{GO}]$$

$$C_{p,p,eff} = [6300(0.531) + 1800(0.700)] / (6300 + 1800)$$

$$C_{p,p,eff} = 0.5686 \text{ kJ kg}^{-1} \text{ K}^{-1}$$

Density of Hybrid Nanofluid

The density of the hybrid nanofluid is calculated using:

$$\rho_{hnf} = (1 - \phi)\rho_{bf} + \phi_{CuO}\rho_{CuO} + \phi_{GO}\rho_{GO}$$

Since $\phi_{CuO} = \phi_{GO} = \phi/2$:

$$\rho_{hnf} = (1 - \phi)\rho_{bf} + \phi\rho_{p,eff}$$

where $\rho_{p,eff} = 4050 \text{ kg m}^{-3}$ and ϕ represents the total hybrid nanoparticle volume fraction.

Specific Heat Capacity of Hybrid Nanofluid

The specific heat capacity was determined using the thermal-equilibrium relation:

$$(\rho C_p)_{hnf} = (1 - \phi)(\rho C_p)_{bf} + \phi_{CuO}(\rho C_p)_{CuO} + \phi_{GO}(\rho C_p)_{GO}$$



Table 2: Required CuO and GO masses for 100 mL base fluid

Total hybrid concentration (vol.%)	Total nanoparticle volume (mL)	CuO volume (mL)	GO volume (mL)	CuO mass (g)	GO mass (g)
0.05	0.050025	0.025013	0.025013	0.15758	0.04502
0.10	0.100100	0.050050	0.050050	0.31532	0.09009
0.25	0.250627	0.125313	0.125313	0.78947	0.22556
0.50	0.502513	0.251256	0.251256	1.58291	0.45226

Alternatively, using effective hybrid-particle properties:

$$(pCp)_{hnf} = (1 - \phi)pb_fCp_{bf} + \phi p_{p,eff}Cp_{p,eff}$$

$$Cp_{hnf} = [(1 - \phi)pb_fCp_{bf} + \phi p_{p,eff}Cp_{p,eff}] / \rho_{hnf}$$

RESULTS AND DISCUSSION

Predicted Density

The predicted density values of the CuO–GO/W–EG hybrid nanofluid are presented in Table 4. The graphical results are plotted directly from the values listed in Table 4.

The density decreases continuously with increasing temperature at all nanoparticle concentrations. This behaviour is associated primarily with the decrease in W–EG base-fluid density with temperature. In contrast, increasing the hybrid nanoparticle concentration increases the predicted density because the effective density of the CuO–GO hybrid solid, 4050 kg m⁻³, is substantially higher than that of the W–EG base fluid. At 55 °C, increasing the hybrid concentration from 0.05 to 0.50 vol.% increases the predicted density from 1028.280 to 1041.884 kg m⁻³.

3.2 Density Enhancement

The percentage density enhancement relative to the base fluid was calculated using:

$$\Delta\rho (\%) = [(\rho_{hnf} - \rho_{bf})/\rho_{bf}] \times 100$$

At 55 °C and 0.50 vol.%,

$$\Delta\rho = [(1041.884 - 1026.768)/1026.768] \times 100 \approx 1.47\%$$

Thus, the addition of 0.50 vol.% hybrid nanoparticles results in a moderate density increase.

Predicted Specific Heat Capacity

The calculated specific heat capacity values are presented in Table 5. The graphical results are plotted directly from the values listed in Table 5.

The calculated specific heat capacity increases with temperature for all nanoparticle concentrations. This follows the temperature-dependent increase in the specific heat of the W–EG base fluid. In contrast, the specific heat capacity decreases as the hybrid nanoparticle concentration increases. The effective specific heat of the CuO–GO solid mixture,

Table 3: Effective properties of the 50:50-by-volume CuO–GO hybrid solid

Property	Value
CuO density	6300 kg m ⁻³
GO density	1800 kg m ⁻³
Effective CuO–GO density, 50:50 volume	4050 kg m ⁻³
CuO specific heat	0.531 kJ kg ⁻¹ K ⁻¹
GO specific heat	0.700 kJ kg ⁻¹ K ⁻¹
Effective CuO–GO specific heat	0.5686 kJ kg ⁻¹ K ⁻¹

Table 4: Predicted density (kg m⁻³) of CuO–GO/W–EG hybrid nanofluids

Temperature (°C)	0.05 vol.%	0.10 vol.%	0.25 vol.%	0.50 vol.%
25	1046.391	1047.893	1052.401	1059.914
30	1042.095	1043.599	1048.114	1055.637
35	1039.524	1041.030	1045.548	1053.078
40	1037.399	1038.906	1043.427	1050.963
45	1033.441	1034.950	1039.477	1047.022
50	1030.335	1031.845	1036.377	1043.930
55	1028.280	1029.791	1034.326	1041.884

Table 5: Predicted specific heat capacity (kJ kg⁻¹ K⁻¹) of CuO–GO/W–EG hybrid nanofluids

Temperature (°C)	0.05 vol.%	0.10 vol.%	0.25 vol.%	0.50 vol.%
25	3.3965	3.3910	3.3747	3.3479
30	3.4035	3.3980	3.3816	3.3545
35	3.4134	3.4079	3.3914	3.3642
40	3.4214	3.4159	3.3993	3.3719
45	3.4304	3.4248	3.4081	3.3805
50	3.4393	3.4337	3.4169	3.3892
55	3.4483	3.4427	3.4258	3.3979

0.5686 kJ kg⁻¹ K⁻¹, is substantially lower than the specific heat of the W–EG base fluid, which is 3.402–3.454 kJ kg⁻¹ K⁻¹ over the investigated temperature range. Consequently, increasing the solid fraction reduces the predicted specific heat capacity of the suspension.

Specific-Heat Reduction

The percentage change in specific heat capacity relative to the base fluid is calculated from:

$$\Delta C_p (\%) = [(C_{p,hnf} - C_{p,bf})/C_{p,bf}] \times 100$$

At 55 °C and 0.50 vol.%,

$$\Delta C_p = [(3.3979 - 3.454)/3.454] \times 100 \approx -1.62\%$$

Therefore, the 0.50 vol.% hybrid nanofluid retains approximately 98.38% of the base-fluid specific heat capacity at 55 °C.

Effect of Temperature on Density

The predicted density decreases as temperature increases from 25 to 55 °C for all concentrations. For example, at 0.50 vol.%, the density decreases from 1059.914 kg m⁻³ at 25 °C to 1041.884 kg m⁻³ at 55 °C. This reduction is primarily related to the thermal expansion of the liquid phase. Increasing temperature increases molecular mobility and average intermolecular spacing, resulting in a reduction in density.

Effect of Temperature on Specific Heat

The predicted specific heat capacity increases with temperature. At 0.50 vol.% concentration, the specific heat increases from 3.3479 kJ kg⁻¹ K⁻¹ at 25 °C to 3.3979 kJ kg⁻¹ K⁻¹

at 55 °C. This trend is primarily controlled by the temperature dependence of the base-fluid specific heat.

Effect of Nanoparticle Concentration on Density

The density increases systematically with increasing hybrid nanoparticle concentration. At 55 °C:

The increase results from replacing a portion of the lower-density W–EG fluid with the higher-density CuO–GO hybrid solid.

Effect of Nanoparticle Concentration on Specific Heat

The specific heat capacity decreases progressively with increasing nanoparticle concentration. At 55 °C:

The decrease is associated with the much lower effective specific heat capacity of the CuO–GO solid phase compared with the W–EG base fluid.

Graphical Representation of the Calculated Properties

The calculated-property figures include the W–EG (60:40) base fluid as the 0 vol.% reference condition. This provides a direct comparison between the base fluid and the CuO–GO/W–EG hybrid nanofluids.

Figure 1 compares the predicted density of the base fluid and hybrid nanofluids over 25–55 °C.

Figure 2 compares the predicted specific heat capacity of the base fluid and hybrid nanofluids over 25–55 °C.

Figures 3 and 4 show the concentration effect at selected temperatures. The W–EG base fluid is explicitly represented at 0 vol.% hybrid nanoparticle concentration.

Engineering Interpretation

Density and specific heat capacity should be considered simultaneously when evaluating a nanofluid for thermal-management applications. Increasing nanoparticle concentration increases density, which may influence

Table 6: Density at 55 °C for different hybrid concentrations

Concentration	Density (kg m ⁻³)
Base fluid	1026.768
0.05 vol.%	1028.280
0.10 vol.%	1029.791
0.25 vol.%	1034.326
0.50 vol.%	1041.884

Table 7: Specific heat at 55 °C for different hybrid concentrations

Concentration	Specific heat (kJ kg ⁻¹ K ⁻¹)
Base fluid	3.4540
0.05 vol.%	3.4483
0.10 vol.%	3.4427
0.25 vol.%	3.4258
0.50 vol.%	3.3979

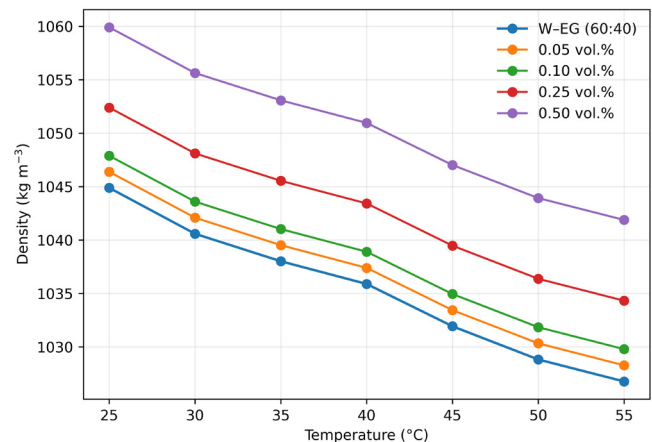


Figure 1: Variation of density with temperature for W–EG base fluid and CuO–GO/W–EG hybrid nanofluids



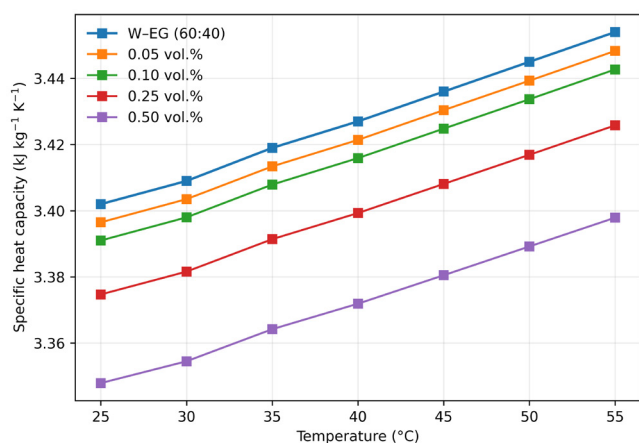


Figure 2: Variation of specific heat capacity with temperature for W-EG base fluid and CuO–GO/W-EG hybrid nanofluids

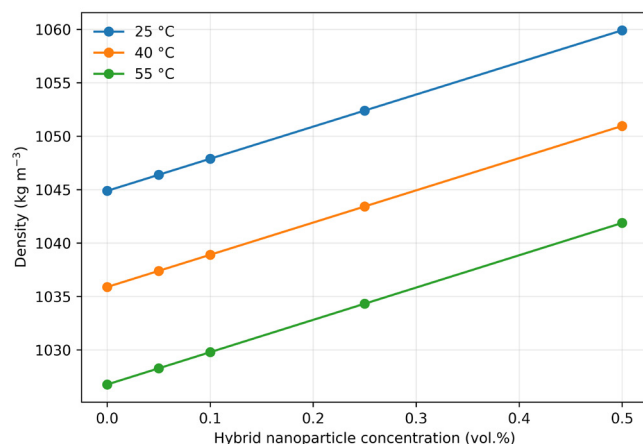


Figure 3: Effect of hybrid nanoparticle concentration on density at selected temperatures; 0 vol.% represents the W-EG base fluid

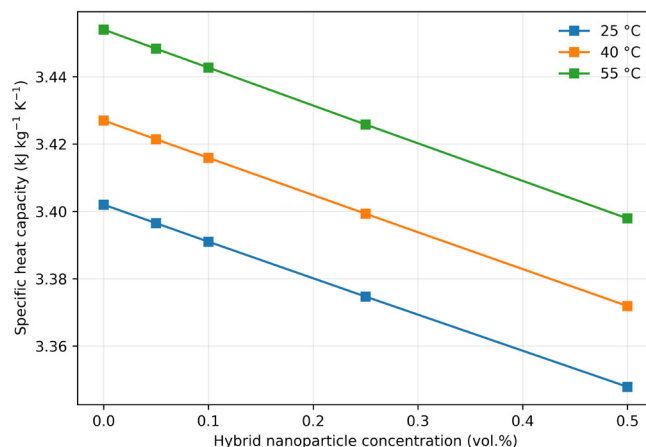


Figure 4: Effect of hybrid nanoparticle concentration on specific heat capacity at selected temperatures; 0 vol.% represents the W-EG base fluid

Reynolds number, pressure drop and pumping requirements. At the same time, the specific heat capacity decreases because of the lower heat-storage capacity of the solid phase compared with the W-EG base fluid. At 0.50 vol.% and 55 °C, the present model predicts a density of $1041.884 \text{ kg m}^{-3}$, a density increase of 1.47%, a specific heat of $3.3979 \text{ kJ kg}^{-1} \text{ K}^{-1}$ and a specific-heat reduction of 1.62%. Density and specific heat alone cannot establish the overall superiority of the hybrid nanofluid; thermal conductivity, viscosity, stability and actual convective heat-transfer performance must also be considered.

CONCLUSIONS

1. A 50:50-by-volume CuO–GO composition was adopted consistently throughout the calculations.
2. Because CuO and GO have different densities, a 50:50 volume ratio corresponds to a 3.5:1 CuO:GO mass ratio.
3. The effective density of the 50:50-by-volume CuO–GO hybrid solid was calculated as 4050 kg m^{-3} .
4. The effective specific heat capacity of the hybrid solid was calculated as $0.5686 \text{ kJ kg}^{-1} \text{ K}^{-1}$.
5. The predicted density decreased with increasing temperature and increased with increasing nanoparticle concentration.
6. At 0.50 vol.% and 55 °C, the predicted density was $1041.884 \text{ kg m}^{-3}$ compared with $1026.768 \text{ kg m}^{-3}$ for the base fluid.
7. The corresponding density enhancement was approximately 1.47%.
8. Specific heat capacity increased with temperature but decreased with increasing nanoparticle concentration.
9. At 0.50 vol.% and 55 °C, the predicted specific heat capacity was $3.3979 \text{ kJ kg}^{-1} \text{ K}^{-1}$ compared with $3.454 \text{ kJ kg}^{-1} \text{ K}^{-1}$ for the base fluid.
10. The corresponding reduction in specific heat capacity was approximately 1.62%.
11. The addition of CuO–GO hybrid nanoparticles produces a moderate increase in density while retaining most of the base-fluid specific heat capacity within the investigated concentration range.
12. Because density and specific heat capacity were model-derived, the present results should be considered theoretical predictions requiring experimental validation.

DATA AVAILABILITY

The density and specific-heat values reported in this manuscript were calculated from the specified thermophysical properties of distilled water, ethylene glycol, CuO and GO using the equations described in the methodology. Direct experimental measurements of density and specific heat capacity were not performed for the present analysis.

FUNDING

This research received no specific external funding.

Conflict of Interest

The authors declare that they have no competing interests.

Ethics Approval

Not applicable.

Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Author Contributions

P. Pradeepa: Conceptualization, methodology, calculations, data analysis and manuscript preparation. M. T. Naik: supervision, review and guidance.

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