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Study on the Different Characteristics of Nano-MgO/Water Nanofluid for Heat Transfer Applications

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The development of efficient thermal management systems has become increasingly important across various industries. This study investigates the thermophysical properties of nano-MgO/water nanofluids, synthesized using a two-step method with sodium dodecyl benzene sulfonate (SDBS) as a stabilizing surfactant. Nano-MgO particles were dispersed in distilled water at varying volume concentrations of 0%, 0.1%, 0.2%, 0.3%, and 0.4%. Comprehensive characterization was conducted to evaluate viscosity, specific heat capacity, density, shear behavior, and thermal conductivity. Results demonstrated that the addition of nano-MgO enhanced the density and thermal conductivity of the base fluid while inducing a modest increase in viscosity. The specific heat capacity exhibited a slight decrease with rising nanoparticle concentration. The rheological studies confirmed that the nanofluids maintained Newtonian behavior across all tested concentrations and shear rates. Furthermore, thermal conductivity improvements were more pronounced at higher temperatures and concentrations, indicating enhanced heat transfer potential. These findings suggest that nano-MgO/water nanofluids, particularly at concentrations around 0.2–0.3 vol.%, offer a promising balance between thermal performance enhancement and manageable flow resistance, making them suitable for a range of heat transfer applications.

Keywords: Nanofluid; heat transfer; nano-MgO; characterization; viscosity

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The growing demand for efficient energy systems and the continuous push toward sustainable technologies have led researchers to explore novel methods for improving thermal management processes [1, 2]. In many industrial, automotive, and electronic systems, heat transfer fluids play a critical role in maintaining operational efficiency and preventing thermal failure. However, conventional fluids such as water, ethylene glycol, and oils often fall short in providing the required thermal conductivity needed for modern, high-performance applications [3, 4]. In order to bridge this gap, the advent of nanotechnology introduced the concept of nanofluids, where the base fluids engineered with suspended nanoparticles to significantly enhance their thermophysical properties [5]. Nanofluids, a term first introduced by Choi in 1995, have since attracted immense research interest due to their superior thermal conductivity, higher heat transfer rates, and better stability compared to traditional coolants [6, 7]. The inclusion of nanoparticles, even in small quantities, can dramatically alter the fluid's behavior, enhancing its ability to absorb, transport, and dissipate heat [8, 9]. Various nanoparticles, including metals, metal oxides, carbides, and carbon-based materials, have been tested to evaluate their impact on fluid properties [10, 11]. Among them, magnesium oxide (MgO) nanoparticles have emerged as particularly promising candidates due to their unique combination of desirable characteristics [12, 13]. Magnesium oxide stands out for its high thermal conductivity, chemical stability, wide availability, and non-toxicity. Moreover, its relatively low cost and compatibility with a variety of base fluids make it an attractive option for large-scale industrial applications [14]. Compared to more expensive and complex nanoparticles like silver or graphene, nano-MgO offers a cost-effective solution without compromising on performance, making it ideal for practical engineering applications.

Given these advantages, a deeper understanding of the behavior of nano-MgO/water nanofluids is crucial for optimizing their use in heat transfer systems.

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Specifically, properties such as viscosity, specific heat capacity, density, shear rate behavior, and thermal conductivity must be thoroughly investigated, as they directly influence the efficiency and reliability of any system employing these fluids [15, 16]. For instance, while higher thermal conductivity improves heat transfer, increased viscosity can lead to higher pumping power requirements, which may offset some of the thermal gains [17]. Therefore, achieving an optimal balance among these properties is key to realizing the full potential of nanofluids in real-world applications. The preparation of stable nanofluids is another critical aspect that impacts their practical usability. Proper dispersion of nanoparticles into the base fluid without significant agglomeration is essential to maintaining consistent thermal and flow behavior. Various preparation techniques, such as two-step methods [18] involving ultrasonic agitation and surfactants, have been developed to ensure uniform distribution and enhance suspension stability. While a growing body of literature explores the thermophysical behavior of various nanofluid combinations [19, 20], relatively fewer studies have focused exclusively on nano-MgO dispersed in water across such a finely resolved range of concentrations. Existing studies often report findings at either very low or relatively high concentrations, making it difficult to capture the nuanced transitions that might occur at intermediate loading levels. This gap in knowledge highlights the need for systematic experimentation and thorough analysis, both of which are central to the present work. Moreover, the performance of nanofluids is influenced by factors such as temperature, particle size, surface treatment of nanoparticles, and the nature of the base fluid. In this study, efforts have been made to control external variables and isolate the effects attributable solely to changes in nano-MgO concentration. By maintaining consistent preparation procedures and using high-purity distilled water as the base fluid, the study ensures that the observed changes in properties can be confidently linked to the addition of nanoparticles rather than other confounding factors. The broader motivation behind this work ties back to the global need for energy-efficient systems. Improved cooling technologies are essential not only for electronics and automotive applications but also for sectors like aerospace, renewable energy, and power generation. In particular, with the rise of electric vehicles, concentrated solar power systems, and high-performance computing, there is an ever-increasing demand for fluids that can effectively manage heat without imposing prohibitive operational costs. Nano-MgO/water nanofluids, if properly understood and engineered, could become a vital component in meeting these demands.

The primary objective of this study is to prepare nano-MgO/water nanofluids by dispersing magnesium oxide nanoparticles at varying volume concentrations of 0%, 0.1%, 0.2%, 0.3%, and 0.4% into distilled water using a two-step method. The prepared nanofluids are then characterized to evaluate key thermophysical properties, including viscosity, specific heat capacity, density, shear rate behavior, and thermal conductivity. By systematically analyzing the variations in such properties with incremental additions of nano-MgO, the study aims to provide a comprehensive understanding of the potential of nano-MgO/water nanofluids for efficient heat transfer applications.

EXPERIMENTAL

Materials

The distilled water was procured from the local petrol stations. The magnesia nanoparticles with an average size between 30 and 50 nm had been acquired from Nanoshel. In order to guarantee the stability of the prepared nano-fluid, and it had been procured from Sun chemicals, Coimbatore. SDBS is an anionic surfactant known for its excellent stabilization capability in aqueous media [21] and hence, it was chosen for its effectiveness in minimizing particle clustering without significantly affecting the thermal properties of the base fluid. Table 1 shows the properties of the water and nano-MgO.

Table 1. Characteristics of the deployed materials.

Characteristics	Distilled water	Nano-MgO
Specific heat (KJ/kgK)	4.18	0.94
Viscosity (cP)	1	-
Thermal conductivity (W/mK)	0.61	55.0
Density (kg/m^3)	1000	3600

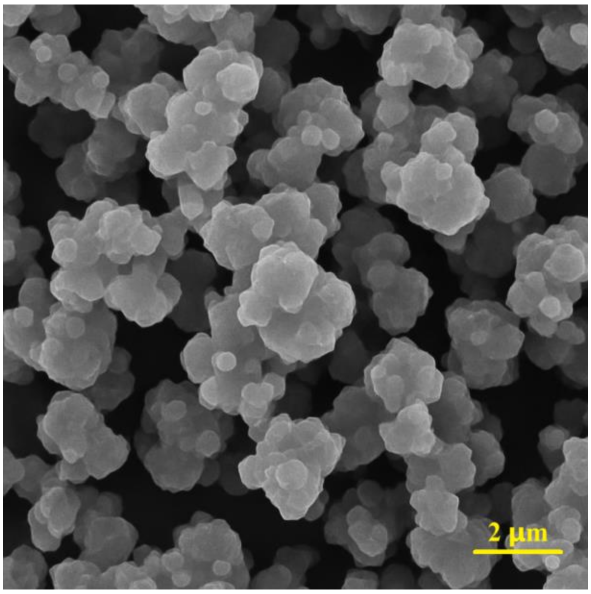

Figure 1. FESEM of the MgO nanoparticles.

Figure 1 illustrates the field emission scanning electron microscopy (FESEM) image of the nano-MgO particles. It can be understood that the particles are in irregular shape rather than spherical. Their surface looks rough and they are in the state of agglomeration. All the materials were used as received without further purification. In order to ensure consistency across all experiments, the same batch of MgO nanoparticles and distilled water was used throughout the study.

Preparation of Nanofluid

The nanofluid (nano-MgO/water) samples had been prepared by carefully dispersing MgO nanoparticles at different volume fractions in distilled water using two-step method [22]. Initially, the required volume fraction of the nano-MgO particles for the decided concentrations (0.1, 0.2, 0.3, and 0.4%) was calculated using Equation (1) [15, 23].

$$\Phi = \frac{V_{nano}}{V_{nano}+V_{fluid}} \quad (1)$$

Where, $\boldsymbol{\Phi}$ denotes volume fraction, V_{nano} is the volume of nano-MgO, and V_{fluid} is the volume of distilled water.

The distilled water was mixed with 0.2 volume fraction of the surfactant and thoroughly mixed. The water solution was kept on the magnetic stirrer, where the predetermined quantity of nano-MgO was introduced into the solution carefully and stirred continuously for 15 minutes, Then, the nanofluid was transferred to a probe sonicator and agitated continuously for 90 minutes in pulsed mode to obtain the nanofluid as a homogeneous solution [24]. The sample details are presented in Table 2.

Table 2. Nano-MgO/water nanofluid samples.

Samples	Nano-MgO (vol.%)	Distilled water (vol.%)
1	0	100
2	0.1	99.9
3	0.2	99.8
4	0.3	99.7
5	0.4	99.6

Characterization of Nanofluid

After preparing the nanofluid samples, a detailed characterization of the samples had been conducted. The viscosity of the nanofluids was measured using a Brookfield rotational viscometer. The measurements were conducted at a constant room temperature to diminish temperature-related variations. The shear rate behavior was evaluated concurrently with viscosity measurements by applying a range of shear rates using the viscometer. Shear stress versus shear rate plots were generated to determine the behaviour of the nanofluids. The specific heat capacity of the samples was measured using a differential scanning calorimeter (DSC). During the assessment, around 10 mg of each nanofluid sample was sealed in standard aluminum pans, and an empty pan was used as the reference. The specific heat values were determined by comparing the heat flow of the nanofluids against that of a sapphire standard.

The density of the samples was measured using a vibrating-tube densimeter. It helps to measure high-precision density readings suitable for nanofluid characterization. The thermal conductivity of the nano-MgO/water nanofluids was measured using TEMPOS thermal properties analyzer.

RESULTS AND DISCUSSION

As discussed in the previous sections, the thermophysical characteristics of the nano-MgO/water nanofluids were systematically evaluated for varying volume fractions of nano-MgO (0%, 0.1%, 0.2%, 0.3%, and 0.4%). The results are discussed in further sections.

Density of Nano-MgO/Water Nanofluids

Figure 2 presents the variation of density with temperature and nano-MgO concentration. As expected, the density of all samples exhibited a decreasing trend with increasing temperature. This behavior is typical of fluids, where thermal expansion leads to a reduction in density. Additionally, the introduction of nano-MgO particles resulted in a systematic increase in density at a given temperature compared to pure water. This increase can be attributed to the higher intrinsic density of MgO nanoparticles relative to the base fluid. Interestingly, the incremental rise in density with nanoparticle concentration was nearly linear, suggesting uniform dispersion and minimal agglomeration due to effective stabilization by SDBS. However, the change in density was relatively modest, even at the maximum loading of 0.4 vol.%, indicating that the nanoparticles enhanced thermal properties without drastically altering the flow dynamics related to density.

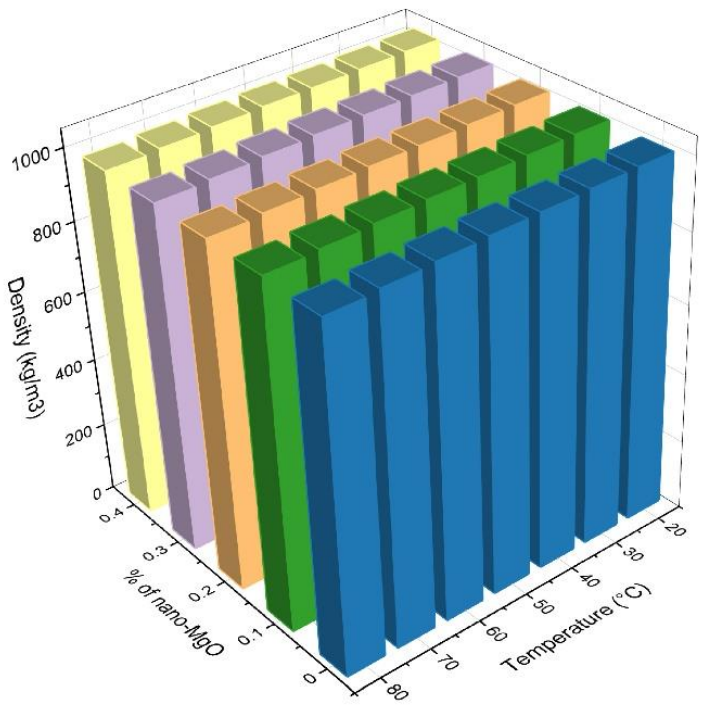

Figure 2. Variation of density with temperature and nano-MgO concentration.

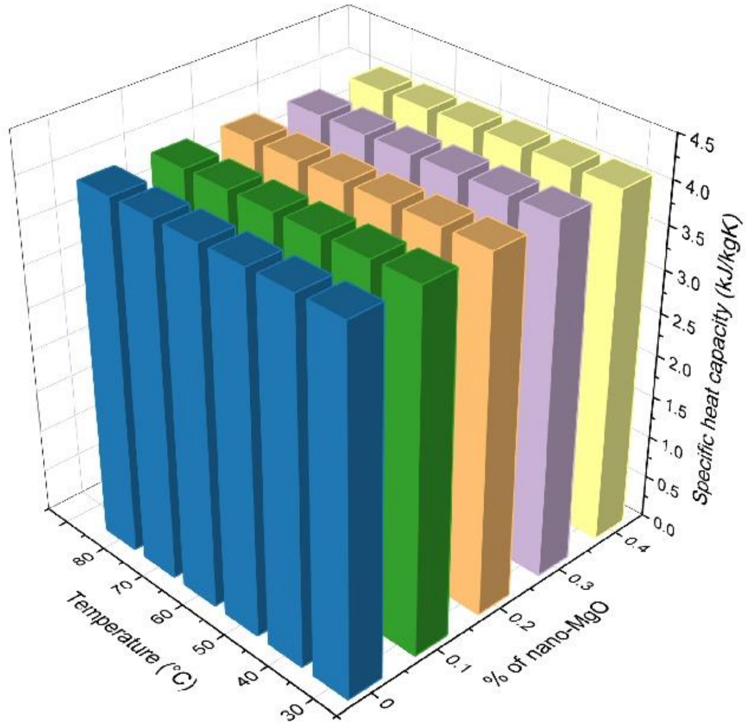

Figure 3. Variation of specific heat with temperature and nano-MgO concentration.

Specific Heat of Nano-MgO/Water Nanofluids

The variation of specific heat with temperature and nano-MgO concentration is shown in Figure 3. It was observed that the specific heat of the nanofluids decreased progressively with an increase in nano-MgO concentration. This behavior is consistent with prior studies, where nanoparticles typically possess lower specific heat compared to the base fluid. As nano-MgO loading increases, the effective heat capacity of the nanofluid decreases. Nevertheless, the reduction in specific heat remained within manageable limits, particularly important for maintaining the fluid's energy storage capacity. It is notable that temperature had a lesser influence on specific heat compared to particle loading, highlighting that nano-MgO's effect is dominant in this regard.

Viscosity of Nano-MgO/Water Nanofluids

Figures 4 and 5 display the variation of viscosity and relative viscosity with temperature and nano-MgO concentration, respectively. It was evident that viscosity decreased as the temperature increased, which is a typical behavior for most liquids due to the reduction in intermolecular forces at higher temperatures. At the same time, the addition of nano-MgO particles led to a noticeable rise in viscosity at all temperatures. The impact of nanoparticle concentration on viscosity was more pronounced at lower temperatures. For instance, at lower temperatures, a 0.4 vol.% nanofluid showed a higher increase in viscosity relative to pure water compared to higher temperatures. This indicates that while nano-MgO enhances heat transfer properties, it also marginally increases the flow resistance, which might require more pumping power in practical applications.

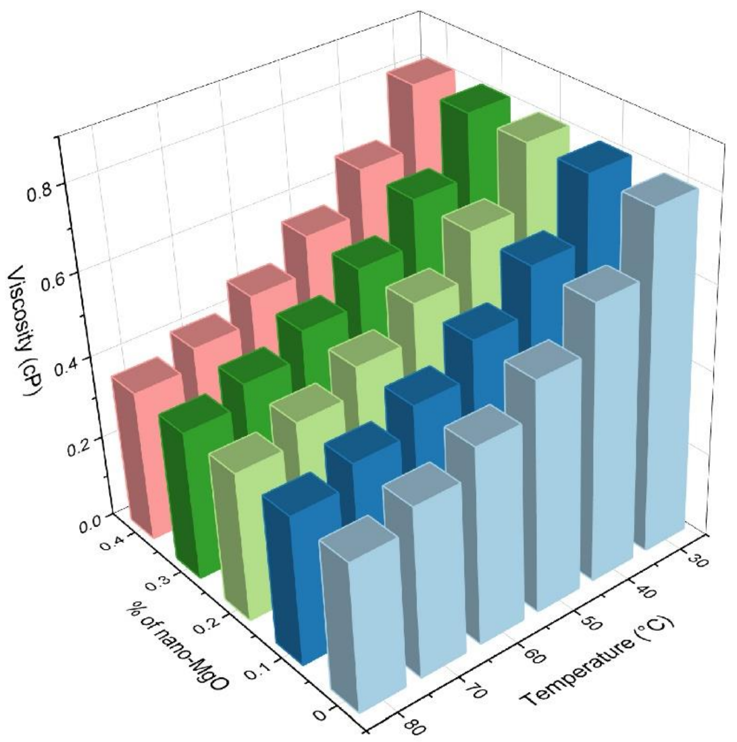

Figure 4. Variation of viscosity with temperature and nano-MgO concentration.

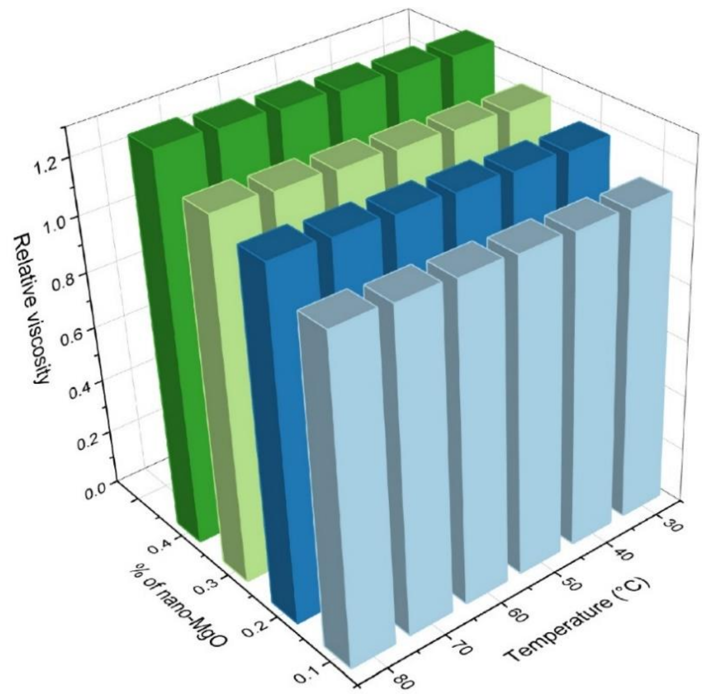

Figure 5. Variation of relative viscosity with temperature and nano-MgO concentration.

Figure 6 further illustrates the percentage enhancement in relative viscosity with nano-MgO concentration. The enhancement followed a near-linear trend, implying that the nanoparticles acted independently without significant clustering that would otherwise cause non-linear viscosity behavior. Even at 0.4 vol.% concentration, the maximum increase in viscosity was within acceptable limits, suggesting that these nanofluids could be used efficiently in thermal systems without incurring a significant penalty on energy consumption due to increased viscosity.

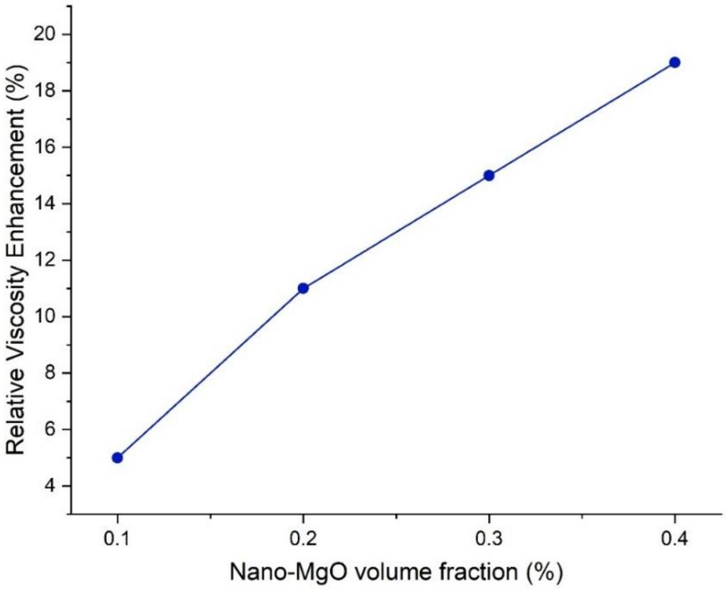

Figure 6. Variation of relative viscosity enhancement % with nano-MgO concentration.

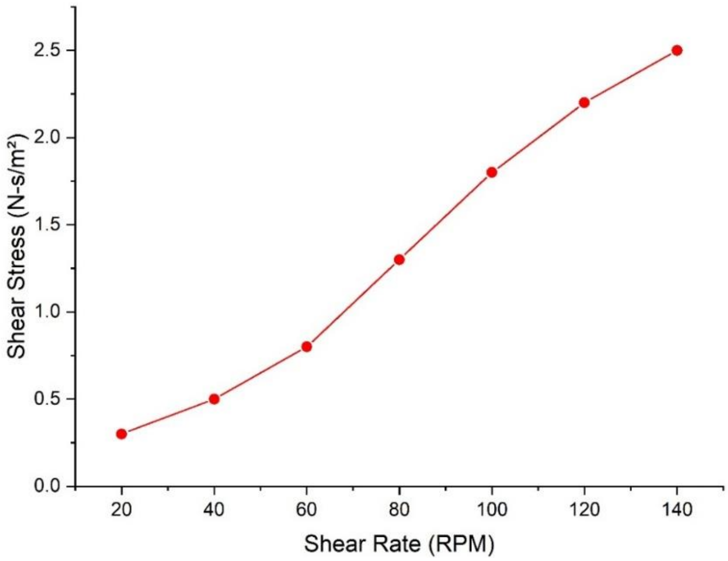

Figure 7. Variation of shear stress with shear rate of a sample with 0.4% nano-MgO.

Shear Behaviour of Nano-MgO/Water Nanofluids

The rheological behavior of the nanofluids was further investigated through shear stress versus shear rate measurements, presented in Figure 7 for the sample with 0.4 vol.% nano-MgO. The relationship between shear stress and shear rate was linear, indicating that the nano-MgO/water nanofluid behaves as a Newtonian fluid across the tested shear rate range. The linearity also implies that the addition of nano-MgO up to 0.4 vol.% did not induce non-Newtonian characteristics such as shear thinning or thickening, which is highly desirable in heat transfer applications where predictable and stable flow behavior is critical.

The shear stress values increased with shear rate, with higher nanoparticle concentrations resulting in slightly higher shear stress values. This behavior aligns with the observed increase in viscosity, as denser fluids resist flow more than less viscous ones. The preservation of Newtonian behavior even at elevated nanoparticle concentrations demonstrates the effectiveness of the dispersion method and the role of SDBS surfactant in preventing agglomeration. The values of the shear stress for the corresponding shear rate are given in Table 3.

Table 3. Shear stress versus shear rate for a sample with 0.4% nano-MgO.

Shear Rate in RPM	Shear Stress in N-s/m^2
20	0.3
40	0.5
60	0.8
80	1.3
100	1.8
120	2.2
140	2.5

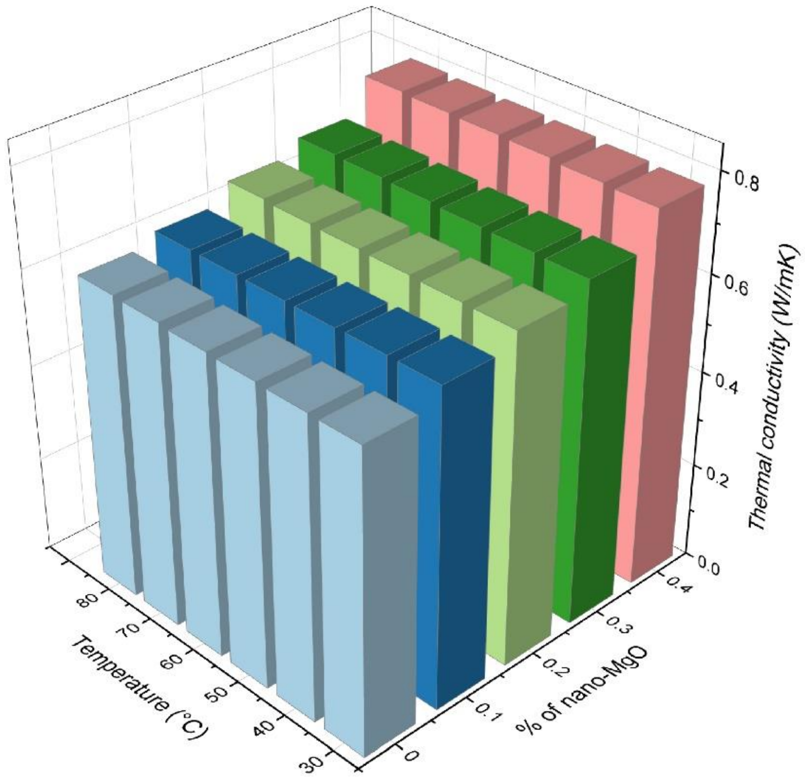

Figure 8. Variation of thermal conductivity with temperature and nano-MgO concentration.

Thermal Conductivity of Nano-MgO/Water Nanofluids

Thermal conductivity results, shown in Figures 8 and 9, reveal the most compelling evidence of the beneficial impact of nano-MgO inclusion. It was observed that thermal conductivity increased consistently with both nanoparticle concentration and temperature. The enhancement of thermal conductivity with increasing nanoparticle loading is attributed to the high intrinsic thermal conductivity of MgO nanoparticles and the effective transfer of thermal energy across the solid-liquid interface facilitated by the surfactant. Moreover, the positive influence of temperature on thermal conductivity suggests that at elevated temperatures, nanofluid performance could further improve due to intensified Brownian motion, which enhances microconvection and promotes energy transfer at the nanoscale. The thermal conductivity enhancement percentage (Figure 9) demonstrates a significant improvement, particularly notable at higher temperatures and higher concentrations. At 0.4 vol. % nano-MgO concentration, the thermal conductivity enhancement was substantial, affirming the potential of these nanofluids in applications requiring efficient heat removal or thermal energy management. Importantly, the observed enhancements were achieved without drastic increases in viscosity or significant reductions in specific heat, balancing the critical parameters needed for effective thermal systems.

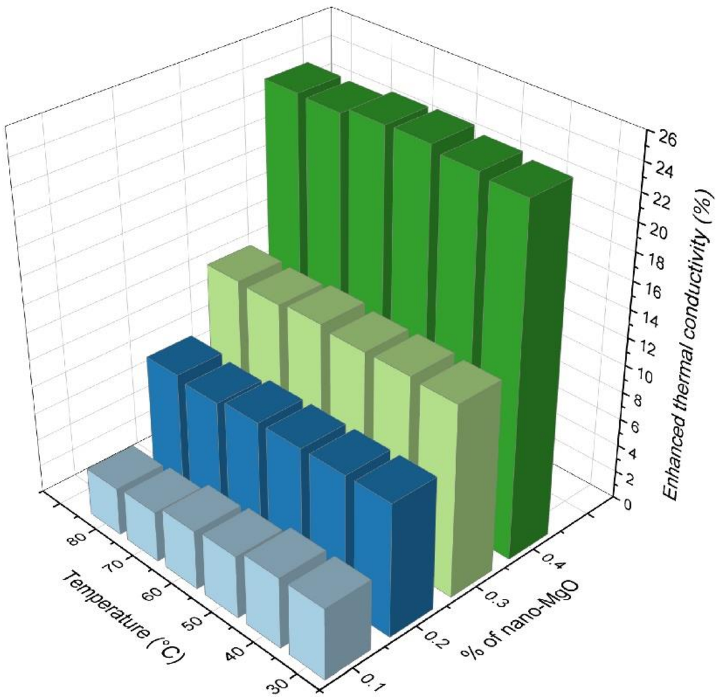

Figure 9. Variation of thermal conductivity enhancement % with temperature and nano-MgO concentration.

The findings from different characterization demonstrate that nano-MgO/water nanofluids exhibit significant improvements in thermophysical properties relevant to heat transfer. The interplay between thermal conductivity, viscosity, and specific heat indicates that an optimal concentration exists where thermal performance is maximized without incurring excessive flow resistance. From the observations, the concentrations around 0.2–0.3 vol.% appear particularly attractive, offering noticeable improvements in thermal conductivity with manageable increases in viscosity. The Newtonian behavior of the nanofluids across all tested concentrations is a significant advantage for engineering applications, as it ensures predictability and ease of system design. Furthermore, the thermal conductivity enhancement observed suggests that even small amounts of nano-MgO can make a meaningful impact, potentially enabling lighter, more compact, and energy-efficient thermal management systems.

CONCLUSION

This study systematically explored the thermophysical behavior of nano-MgO/water nanofluids prepared at different volume concentrations (0.1, 0.2, 0.3, and 0.4%) of nano-MgO.

- The results revealed that the incorporation of nano-MgO particles significantly improved the thermal conductivity of the base fluid, especially at elevated temperatures, without introducing substantial penalties in viscosity or altering the fluid's Newtonian characteristics.
- Although the specific heat capacity showed a minor reduction with increased nanoparticle concentration, the overall energy transport efficiency of the fluid was enhanced due to improved thermal conductivity.
- The slight increase in density and viscosity with nanoparticle addition was linear and manageable, supporting ease of integration into existing thermal systems.
- Among the tested concentrations, 0.2–0.3 vol. % emerged as an optimal range for achieving a favorable balance between thermal enhancement and fluid dynamics.

These insights highlight the potential of nano-MgO/water nanofluids as an effective alternative for advanced heat transfer applications, contributing to the development of more compact, efficient, and reliable cooling technologies.

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