

RESEARCH ARTICLE

# Preparation and Characterization of Beryllium Oxide–Diethylene Glycol Nanofluids for Enhanced Thermal Conductivity

P. Prakash <sup>1</sup>, J. Catherine Grace John <sup>2</sup>, T. Merita Anto Britto <sup>3</sup>, B. Rohini <sup>4</sup>, A. Kingson Solomon Jeevaraj <sup>5,\*</sup>

**ABSTRACT:** This study focuses on the synthesis, characterization, and preparation of beryllium oxide (BeO) nanoparticles and their subsequent dispersion in diethylene glycol to form nanofluids. BeO nanoparticles were synthesized via a chemical precipitation method and calcined at 840°C for four hours. The nanoparticles were characterized using X-ray diffraction (XRD) and scanning electron microscopy (SEM), revealing an average crystallite size of 22.72 nm. Five concentrations of BeO nanoparticles, ranging from 0.001 to 0.005 weight percent, were dispersed in diethylene glycol using a probe ultrasonicator to form stable nanofluids. The molecular interactions within the nanofluids were studied through ultrasonic velocity, thermal conductivity, and viscosity measurements. The results demonstrate enhanced thermal conductivity at room temperature, with the highest value observed for the nanofluid with 0.001 wt% BeO, suggesting its potential for heat transfer applications. Viscosity measurements further revealed a decrease in peak values, indicating effective nanoparticle-fluid interactions. These findings offer valuable insights into the development of nanofluids with optimized thermal properties for industrial cooling applications.

**Keywords:** Beryllium oxide nanoparticles, Nanofluids, Acoustic parameters, Thermal conductivity

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## 1. INTRODUCTION

The prefix "nano" refers to "one billionth" or  $10^{-9}$  of a meter, a scale at which materials often exhibit unique and novel properties distinct from their bulk counterparts. The concept

of nanotechnology was famously introduced by Nobel laureate Richard P. Feynman in his 1959 lecture, "There's Plenty of Room at the Bottom," where he described the potential to manipulate matter at the atomic level. Since then, nanotechnology has revolutionized various fields, including biology, chemistry, physics, medicine, materials science, and engineering. Today, nanotechnologies are recognized for their wide range of potential applications, including stronger and lighter materials, targeted drug delivery, water purification, energy storage, and electronic devices [1].

At the nanoscale, materials behave differently due to the dominance of surface forces, quantum effects, and their significantly high surface-area-to-volume ratio. For example, materials that are non-reactive or weak at the bulk scale may exhibit enhanced chemical reactivity, strength, or electrical conductivity when reduced to the nanoscale [2]. These changes can give rise to properties like superparamagnetism, high catalytic activity, and extraordinary mechanical strength,

<sup>1</sup> Department of Physics, Suguna College of Engineering, Coimbatore 641014, Tamil Nadu, India.

<sup>2</sup> Department of Mathematics, Karunya Institute of Technology and Sciences, Coimbatore - 641114, Tamil Nadu, India.

<sup>3</sup> Department of Physics, Alagappa Government Arts College, Karaikudi -630 003, Tamil Nadu, India.

<sup>4</sup> Department of Physics, New Horizon College of Engineering, Bangalore -560103 Karnataka, India.

<sup>5</sup> Department of Physics, LRG Government Arts College for Women, Tirupur 641604, Tamil Nadu, India.

\* Author to whom correspondence should be addressed:  
[prakashjerome2007@gmail.com](mailto:prakashjerome2007@gmail.com) (P. Prakash)  
[drkingson@gmail.com](mailto:drkingson@gmail.com) (A. K. S. Jeevaraj)

making nanomaterials highly sought after in diverse industries [3]. Nanomaterials can be produced using either a "top-down" or "bottom-up" approach. The top-down method involves physically breaking down bulk materials into nanoscale particles through processes like milling or grinding. However, this method is energy-intensive and often results in non-uniform particle shapes and sizes, limiting its efficiency for many applications [4].

In contrast, the bottom-up approach involves building structures atom by atom or molecule by molecule, allowing for greater control over the size, shape, and distribution of the nanoparticles produced. This method is widely used in chemical synthesis to create homogeneous nanomaterials and is integral to the development of nanostructures and nanodevices [5]. Traditional techniques for synthesizing nanoparticles include gas-phase reactions, pyrolysis, precipitation, and crystallization. In gas-phase synthesis, for instance, sputtering and clustering steps are employed to create nanoparticles by breaking up solid precursors into molecular-sized particles, which are then cooled and condensed [6]. Another approach is arc discharge, which utilizes electrical energy to vaporize a solid precursor and form nanopowders. This technique is versatile and can produce a wide range of nanomaterials with different chemical compositions [7].

Nanofluids, a prominent subclass of nanomaterials, are formed by suspending nanoparticles in a base fluid. These fluids have garnered significant attention due to their enhanced heat transfer capabilities compared to traditional fluids. The term "nanofluid" combines the Latin prefix "nano" ( $10^{-9}$ ) and "fluid" to indicate the suspension of nanoparticles in a liquid medium [8]. Common base fluids include water, ethylene glycol, transformer oil, and synthetic oils. Nanoparticles dispersed in these fluids can significantly alter their thermal and rheological properties, making them suitable for use in various heat transfer applications [9].

The two primary methods for producing nanofluids are the one-step and two-step processes. The one-step physical vapor condensation method synthesizes and disperses nanoparticles simultaneously, which reduces agglomeration and enhances stability. However, incomplete reactions or residual reactants may remain, affecting the performance of the nanofluids [10]. The two-step process, which involves first creating nanoparticles as dry powders and then dispersing them into a base fluid, is the most commonly used and cost-effective technique for large-scale production. However, one challenge with this method is the tendency of nanoparticles to agglomerate due to their high surface area and surface activity [11].

Nanofluids have emerged as an innovative solution for enhancing heat transfer in industrial processes. The need for efficient heat transfer is critical in many applications, such as cooling systems, heat exchangers, radiators, and electronic devices. Traditional fluids, such as water and oils, have limited thermal conductivity, which constrains their ability to transfer heat efficiently. Nanofluids, on the other hand, possess superior thermal conductivity, diffusivity, and convective heat transfer coefficients due to the addition of

nanoscale particles [12]. The enhanced properties of nanofluids stem from the high surface area of the nanoparticles, which allows for increased interaction with the base fluid and improved energy transfer. The development of nanofluids has thus sparked interest in various fields, from automotive cooling systems to advanced electronics [13].

One of the key advantages of nanofluids is their ability to improve the efficiency and longevity of heat transfer equipment. In cooling applications, nanofluids can reduce the energy consumption of systems while preventing overheating, which is a critical issue in industries like power generation, electronics, and automotive engineering [14]. Additionally, nanofluids can be customized by selecting different nanoparticles (such as metals, metal oxides, or carbon-based materials) to tailor their properties to specific applications. For instance, metal oxide nanoparticles like alumina and titania are commonly used in nanofluids for their high thermal conductivity and chemical stability [15].

However, the practical implementation of nanofluids also presents challenges. Nanoparticle aggregation, sedimentation, and stability over time are significant concerns, as these factors can affect the fluid's performance. Agglomeration of nanoparticles can increase the viscosity of the fluid, which may require higher pumping power and reduce the overall heat transfer efficiency. Additionally, the long-term stability of nanofluids remains a challenge, as particles can settle out of suspension during prolonged use [16]. Therefore, research is ongoing to develop techniques that enhance the stability and dispersibility of nanoparticles within base fluids. Surfactants, surface modification, and ultrasonication are commonly used methods to address these issues [17].

In this paper, we will examine the development, characterization, and heat transfer performance of nanofluids, with a focus on diethylene glycol-based BeO nanofluids. The study will present the synthesis of BeO nanofluids at various concentrations and analyze their rheological and acoustic properties at room temperature. Additionally, we will discuss the thermal conductivity and viscosity measurements of the nanofluids, evaluating their potential for improving heat transfer in practical applications. By examining the influence of nanoparticle concentration on the thermophysical properties of BeO nanofluids, this research aims to provide insights into the optimization of nanofluids for enhanced heat transfer performance [18, 19].

## 2. EXPERIMENTAL DETAILS

The synthesis of beryllium oxide (BeO) nanoparticles was achieved using the chemical precipitation technique. The process began by combining 50 mL of double-distilled water with 1 mol of stoichiometric beryllium sulfate ( $\text{BeSO}_4$ ), followed by stirring for 30 minutes using a magnetic stirrer to ensure a homogenous mixture. Concurrently, a solution of sodium hydroxide (NaOH) was prepared by dissolving 2.5 mol of NaOH in double-distilled water. The prepared NaOH

solution was then gradually added to the beryllium sulfate solution while maintaining constant stirring with a magnetic stirrer. This gradual addition took place over the course of three hours to ensure thorough mixing and to control the reaction rate. After the NaOH addition was completed, the solution was further stirred for several hours [14].

To enhance the dispersion of nanoparticles in the solution, sonication was applied. The solution was sonicated for 45 minutes, with a 5-minute break every 15 minutes, to prevent excessive heat buildup. Sonication helps in breaking down agglomerates and ensures a uniform suspension of fine nanoparticles within the solution. The resulting white precipitate was left undisturbed for 12 hours to allow for proper settling. Following the settling process, the precipitate was rinsed multiple times with distilled water to remove any residual impurities, filtered, and then dried at 80°C. This drying process produced a fine nanopowder with good grain structure. To further improve the crystalline structure, the dried nanopowder was calcined at 840°C for two hours. After calcination, the material was finely ground to produce high-quality beryllium oxide nanopowder suitable for further analysis [15].

The chemical formula of diethylene glycol ( $C_4H_{10}O_3$ ), used as the base fluid, is illustrated in Figure 1. Diethylene glycol is a colorless, odorless, low-volatility compound with low viscosity, making it an ideal candidate for nanofluid preparation. It is highly soluble in water and several organic liquids, and its chemical reactivity and solubility make it useful for various applications. Diethylene glycol is particularly effective as a medium for convective heat transfer, commonly employed in cooling systems for liquid-cooled computers and vehicles [16]. Additionally, it is used in geothermal heating systems, air conditioning systems with external components, and systems that must operate at temperatures below the freezing point of water.

To prepare nanofluids, six distinct weight concentrations of the BeO nanopowder were used: 0.001, 0.001, 0.002, 0.003, 0.004, and 0.005 wt%.

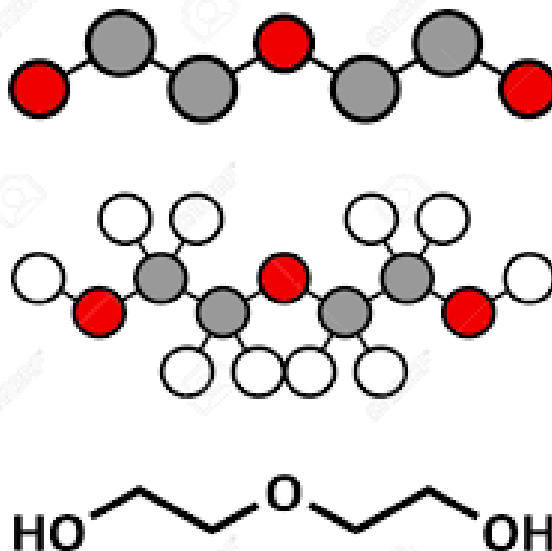


Fig. 1. Structure of Diethylene Glycol.

The nanopowder was carefully dispersed into diethylene glycol (as shown in Figure 2). Due to the slightly viscous nature of diethylene glycol, the nanofluid underwent sonication to ensure that the nanoparticles were uniformly dispersed and did not agglomerate. Sonication is essential in this process to maintain the stability of the nanofluid by preventing particle clumping. After 45 minutes of sonication, the nanofluid exhibited a visibly more homogenous appearance compared to its pre-sonicated form. These prepared nanofluids were then subjected to various characterization techniques [17].



Fig. 2. Photographic image of BeO:diethylene glycol nanofluids.

The acoustical parameters of the nanofluids were calculated using the following relations:

**Adiabatic Compressibility ( $\beta$ ):** This represents the fractional decrease in volume per unit increase in pressure when no heat is exchanged.

$$\beta = 1/U^2\rho \quad (1)$$

where  $U$  is the ultrasonic velocity and  $\rho$  is the density [18].

**Intermolecular Free Length ( $L_f$ ):** This refers to the distance between adjacent molecular surfaces.

$$L_f = K\beta^{1/2} \quad (2)$$

where  $K$  is a temperature-dependent constant [19].

**Free Volume ( $V_f$ ):** This is the volume available for molecular movement.

$$V_f = (M_{eff}U/K\eta)^{3/2} \quad (3)$$

where  $M_{eff}$  is the effective molecular weight,  $\eta$  is the viscosity, and  $K$  is a constant [20].

**Acoustic Impedance ( $Z$ ):** This is a key physical property that facilitates the study of molecular interactions.

$$Z = \rho U \quad (4)$$

where  $\rho$  is the density and  $U$  is the velocity [21].

**Relaxation Time ( $\tau$ ):** This is the time required for the system to dissipate the energy from excitation into translational energy.

$$\tau = 4\eta/3\rho U^2 \quad (5)$$

where  $\eta$  is the viscosity [22].

**Internal Pressure ( $\pi_i$ ):** This is the cohesive force resulting from molecular interactions, including both attractive and repulsive forces.

$$\pi_i = bRT [K\eta/U]^{1/2}\rho^{2/3}/M^{7/6} \quad (6)$$

where  $b$  is a constant,  $R$  is the gas constant,  $T$  is the temperature, and  $M$  is the molecular weight [22].

**\*Gibbs Free Energy ( $\Delta G^*$ ):** This thermodynamic property corresponds to the energy available to do work at a constant temperature and pressure.

$$\Delta G^* = kT \cdot \ln(kT\tau/h) \quad (7)$$

where  $k$  is Boltzmann's constant,  $T$  is temperature,  $\tau$  is

relaxation time, and  $h$  is Planck's constant [22].

**Molar Sound Velocity (Rao's Constant,  $R$ ):** This constant represents the intensity of molecular interactions.

$$R = (M/\rho) U^{1/3} \quad (8)$$

where  $M$  is the molecular weight and  $\rho$  is the density [22].

**Molar Compressibility (Wada's Constant,  $W$ ):** This is a measure of molecular compressibility.

$$W = (M/\rho) \beta^{-1/7} \quad (9)$$

where  $M$  is the molecular weight and  $\beta$  is adiabatic compressibility [21].

The parameters derived from these equations will be discussed in subsequent sections, focusing on the thermophysical properties of the BeO nanofluids and their potential applications in heat transfer systems. The results obtained from these calculations provide insight into the molecular interactions and behaviors of nanofluids, which are critical for optimizing their use in practical applications.

## 3. RESULTS AND DISCUSSION

### 3.1. X-ray diffraction analysis

The structural analysis of the synthesised beryllium oxide (BeO) nanoparticles was carried out using X-ray diffraction (XRD), as shown in Figure 3. The XRD pattern obtained from the sample confirms the crystalline nature of the material. A JEOL XRD-6000 diffractometer with Cu-K $\alpha$  radiation ( $\lambda = 0.15406$  nm) was used to record the diffraction pattern over the  $2\theta$  range of  $20^\circ$  to  $80^\circ$ . The peaks in the XRD spectrum were compared with reference data from the Joint Committee on Powder Diffraction Standards (JCPDS), specifically file number 350818. The peaks correspond well with those listed in the JCPDS, verifying the synthesis of BeO nanoparticles in the hexagonal phase.

Notably, three prominent peaks were observed at  $2\theta$  values of  $38.03^\circ$ ,  $41.01^\circ$ , and  $43.70^\circ$ , which correspond to the (100), (002), and (41) planes, respectively. These diffraction peaks are characteristic of hexagonal beryllium oxide, indicating that the material has a highly ordered crystal structure. The sharpness and intensity of the peaks provide further evidence of the high crystallinity of the synthesised nanoparticles. Additionally, the broadening of the peaks is inversely related to the crystallite size, which can be calculated using the Scherrer equation:

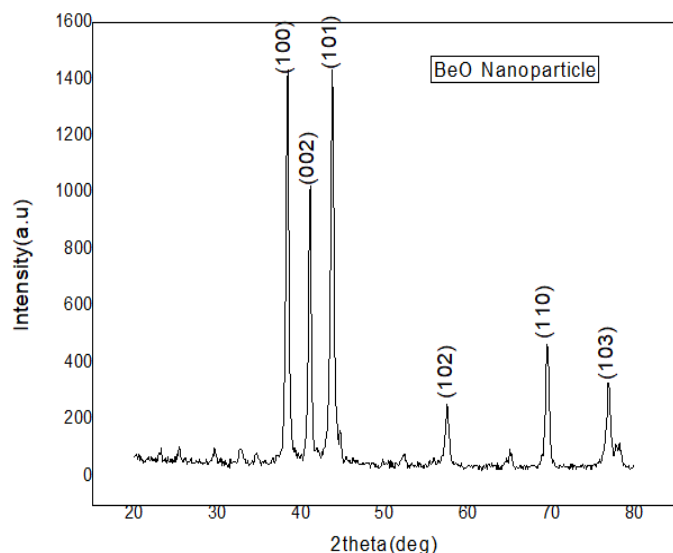
$$D = K\lambda / \beta \cos\theta K\lambda \quad (10)$$

where  $D$  is the crystallite size,  $K$  is the Scherrer constant (typically 0.9),  $\lambda$  is the wavelength of the X-ray radiation (0.15406 nm),  $\beta$  is the full width at half maximum (FWHM)



of the peak in radians, and  $\theta$  is the Bragg angle. Applying this formula, the average crystallite size was found to be approximately 22.72 nm. This nanoscale size confirms that the material was successfully synthesised in a nanoparticulate form, which is essential for applications that require a high surface area-to-volume ratio, such as catalysis and heat transfer. The crystallinity of the material is further evidenced by the absence of any amorphous or secondary phases in the XRD pattern, highlighting the purity and well-defined structure of the BeO nanoparticles.

The hexagonal structure of BeO is particularly advantageous for certain applications due to its high thermal stability and excellent mechanical properties. In many advanced material systems, such as those used in thermal management or electronics, crystalline hexagonal BeO is preferred due to its unique combination of electrical insulation and high thermal conductivity. The formation of BeO in the hexagonal phase is a key achievement in this synthesis, as it enables the material to be used in high-performance environments.



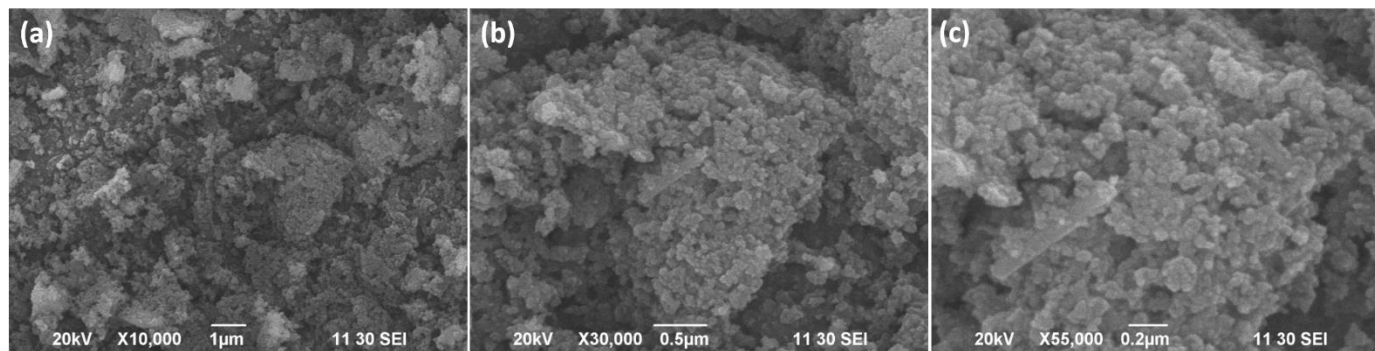
**Fig. 3.** XRD of beryllium oxide nanoparticles.

### 3.2. Scanning Electron Microscopy (SEM) Analysis

The surface morphology of the BeO nanoparticles was further investigated using scanning electron microscopy (SEM), as depicted in Figure 4. SEM analysis provides a detailed visualization of the particles' size, shape, and distribution. The image captured at 30,000x magnification reveals a uniform and well-dispersed arrangement of BeO nanoparticles. The particles exhibit a consistent hexagonal geometry, in line with the structural information obtained from the XRD analysis. This uniformity in shape and size distribution suggests that the synthesis process was well-controlled, leading to homogeneously distributed particles with minimal agglomeration.

The hexagonal shape of the particles, as observed in the SEM image, is characteristic of the crystal structure of BeO, confirming that the nanoparticles have retained their hexagonal phase after synthesis and calcination at 840°C. The high degree of crystallinity observed in the XRD pattern is supported by the clear, distinct boundaries between particles in the SEM image. This sharp delineation of particles indicates that they have well-defined surfaces, which is advantageous for applications that require high surface reactivity, such as catalysis or adsorption processes.

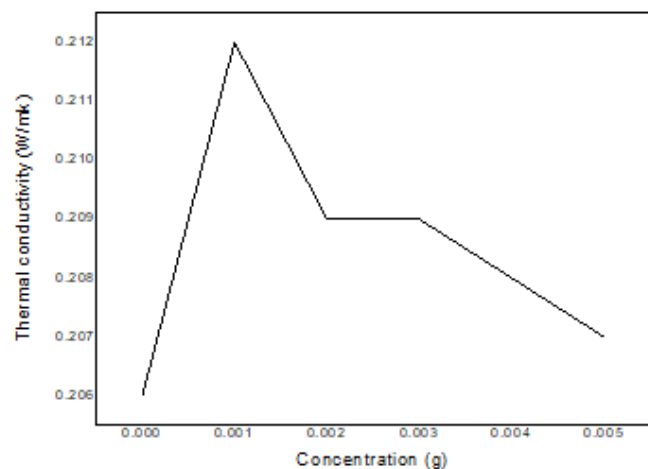
The calcination process at 840°C appears to have played a critical role in defining the morphology and crystallinity of the BeO nanoparticles. High-temperature calcination typically promotes the growth of crystalline phases while eliminating any organic or unwanted impurities from the precursor material. The result is the formation of well-ordered, crystalline nanoparticles with a uniform shape. This process also enhances the mechanical properties of the material, making it suitable for high-temperature and high-pressure applications. Moreover, the SEM image shows that the BeO nanoparticles are free from significant agglomeration, which is often a challenge in nanoparticle synthesis. Agglomeration can lead to a reduction in the effective surface area of the nanoparticles, thereby limiting their performance in various applications. The absence of agglomeration in this sample suggests that the synthesis method employed was effective in producing stable, dispersed nanoparticles.



**Fig. 4.** SEM image of beryllium oxide nanoparticles.

### 3.3. Thermal Conductivity of BeO Nanofluids

Thermal conductivity is one of the most critical parameters for evaluating the potential application of nanofluids in heat transfer systems. The thermal conductivity of the BeO nanofluids was measured using a KD2 Pro Thermal Property Analyser at various weight concentrations of BeO nanoparticles dispersed in diethylene glycol. The results, shown in Figure 5, indicate a clear relationship between nanoparticle concentration and thermal conductivity.



**Fig. 5.** Thermal conductivity vs concentration curve for the beryllium oxide nanoparticles.

As the concentration of BeO nanoparticles increases, the thermal conductivity of the nanofluids initially rises, reaching a peak at 0.001 wt%, where the highest conductivity value of 0.212 W/m.K was recorded. This increase can be attributed to the enhanced thermal transport properties of the nanoparticles, which improve heat conduction through the fluid. The addition of nanoparticles to a base fluid increases its effective thermal conductivity by introducing solid heat-conducting pathways within the liquid. However, beyond 0.001 wt%, the thermal conductivity begins to decline, reaching its lowest value at 0.005 wt%. This decrease can be explained by the agglomeration of nanoparticles at higher concentrations, which disrupts the efficient heat transfer pathways within the fluid. At higher concentrations, the nanoparticles tend to cluster together, reducing their effective surface area and leading to a reduction in thermal conductivity. Additionally, the formation of nanoparticle clusters increases the fluid's viscosity, which may also contribute to the observed reduction in thermal conductivity.

This behavior highlights the importance of optimizing nanoparticle concentration when designing nanofluids for thermal management applications. The peak thermal conductivity at 0.001 wt% suggests that this concentration provides the optimal balance between particle dispersion and thermal transport efficiency. This concentration is, therefore, ideal for applications such as heat exchangers or cooling systems, where high thermal conductivity is essential for efficient heat dissipation.

The thermal conductivity measurements are summarized in Table 1, which provides a detailed breakdown of the conductivity values for each concentration. These results confirm that the thermal properties of the BeO nanofluids can be tuned by adjusting the nanoparticle concentration, allowing for tailored performance in specific applications.

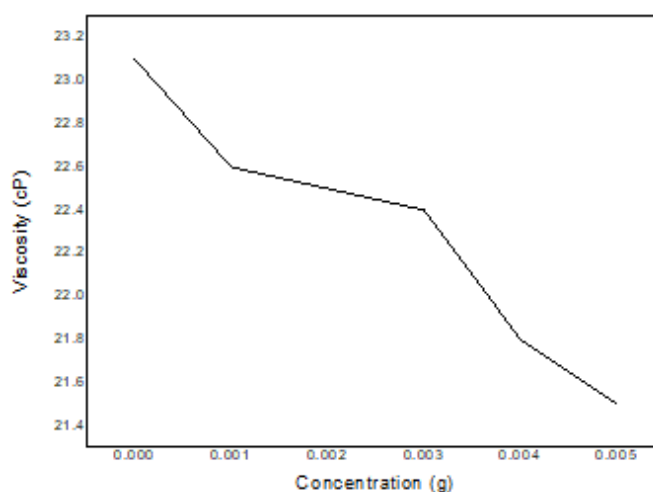
**Table 1.** Thermal Conductivity of BeO Nanofluids at Different Concentrations.

Weight Concentration (g)	Conductivity (W/m.K)
0.000	0.206
0.001	0.212
0.002	0.209
0.003	0.209
0.004	0.208
0.005	0.207

### 3.4. Viscosity Studies of BeO Nanofluids

The viscosity of a nanofluid is another key parameter that affects its performance in heat transfer and fluid flow applications. The viscosity of the BeO nanofluids was measured using a rheometer at different concentrations of BeO nanoparticles, and the results are shown in Figure 6.

As expected, the viscosity of the nanofluids decreases with increasing nanoparticle concentration. This inverse relationship between viscosity and concentration is somewhat counterintuitive, as one might expect the addition of solid particles to increase the fluid's resistance to flow. However, in this case, the interaction between the nanoparticles and the diethylene glycol base fluid appears to reduce the fluid's overall viscosity.



**Fig. 6.** Viscosity vs concentration curve for the beryllium oxide nanoparticles.

The viscosity measurements for each concentration are presented in Table 2, which shows that the viscosity decreases from 23.1 cP at 0 wt% to 21.5 cP at 0.005 wt%. This reduction in viscosity may be attributed to the specific interactions between the nanoparticles and the fluid molecules, which reduce the internal friction within the fluid. The well-dispersed nanoparticles create slip planes within the fluid, allowing it to flow more easily, even at higher concentrations.

This decrease in viscosity is beneficial for practical applications, as lower viscosity fluids are easier to pump and circulate in heat transfer systems. However, it is important to note that while the reduction in viscosity enhances the flow properties of the fluid, it may also reduce the effectiveness of nanoparticle-fluid interactions, potentially limiting the thermal conductivity at higher concentrations.

**Table 2.** Viscosity of BeO Nanofluids at Different Concentrations.

Weight Concentration (g)	Viscosity (cP)
0.000	23.1
0.001	22.6
0.002	22.5
0.003	22.4
0.004	21.8
0.005	21.5

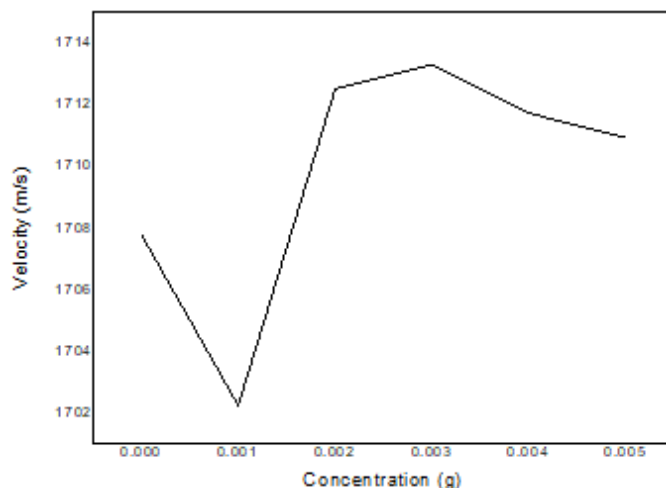
The reduction in viscosity, coupled with the enhancement of thermal conductivity at lower concentrations, highlights the potential of BeO nanofluids as advanced heat transfer fluids.

### 3.5. Ultrasonic Studies

Ultrasonic studies provide crucial insights into the molecular interactions and physical properties of nanofluids. In this study, the ultrasonic velocity of the BeO glycol nanofluids was measured at room temperature across six different weight concentrations, ranging from 0.000 to 0.004 g, to understand the effects of nanoparticle concentration on sound propagation in the fluid (Figure 7). These measurements allow for the calculation of several acoustical parameters, such as adiabatic compressibility, free length, acoustic impedance, and free volume, which are essential for assessing the nanofluids' potential applications, particularly in heat transfer systems.

Table 3 shows the relationship between nanoparticle concentration and the measured ultrasonic velocity. The data demonstrates that the velocity decreases initially at 0.001 g concentration (1702.266 m/s) compared to the base fluid without nanoparticles (1707.774 m/s). However, as the nanoparticle concentration increases to 0.002 g, there is a notable increase in velocity to 1712.524 m/s, indicating that the particles have begun to influence the fluid's internal structure and molecular dynamics. This trend continues at 0.003 g, with the highest velocity recorded at 1713.319 m/s.

At 0.004 g, the velocity slightly decreases to 1711.731 m/s, suggesting that an optimal concentration exists where the nanoparticle-fluid interaction is most effective. The observed fluctuation in ultrasonic velocity can be attributed to changes in molecular interactions within the nanofluids. At lower concentrations, nanoparticles disrupt the intermolecular forces in diethylene glycol, leading to a decrease in velocity. However, as the concentration increases, the nanoparticles form more stable suspensions, enhancing intermolecular interactions and contributing to a rise in velocity. The slight decrease at the highest concentration could be due to agglomeration of nanoparticles, which may hinder wave propagation.



**Fig. 7.** Velocity vs concentration curve for the beryllium oxide nanoparticles.

**Table 3.** Velocity of of BeO Nanofluids at Different Concentrations.

Weight Concentration (g)	Velocity (U)
0.000	1707.774
0.001	1702.266
0.002	1712.524
0.003	1713.319
0.004	1711.731

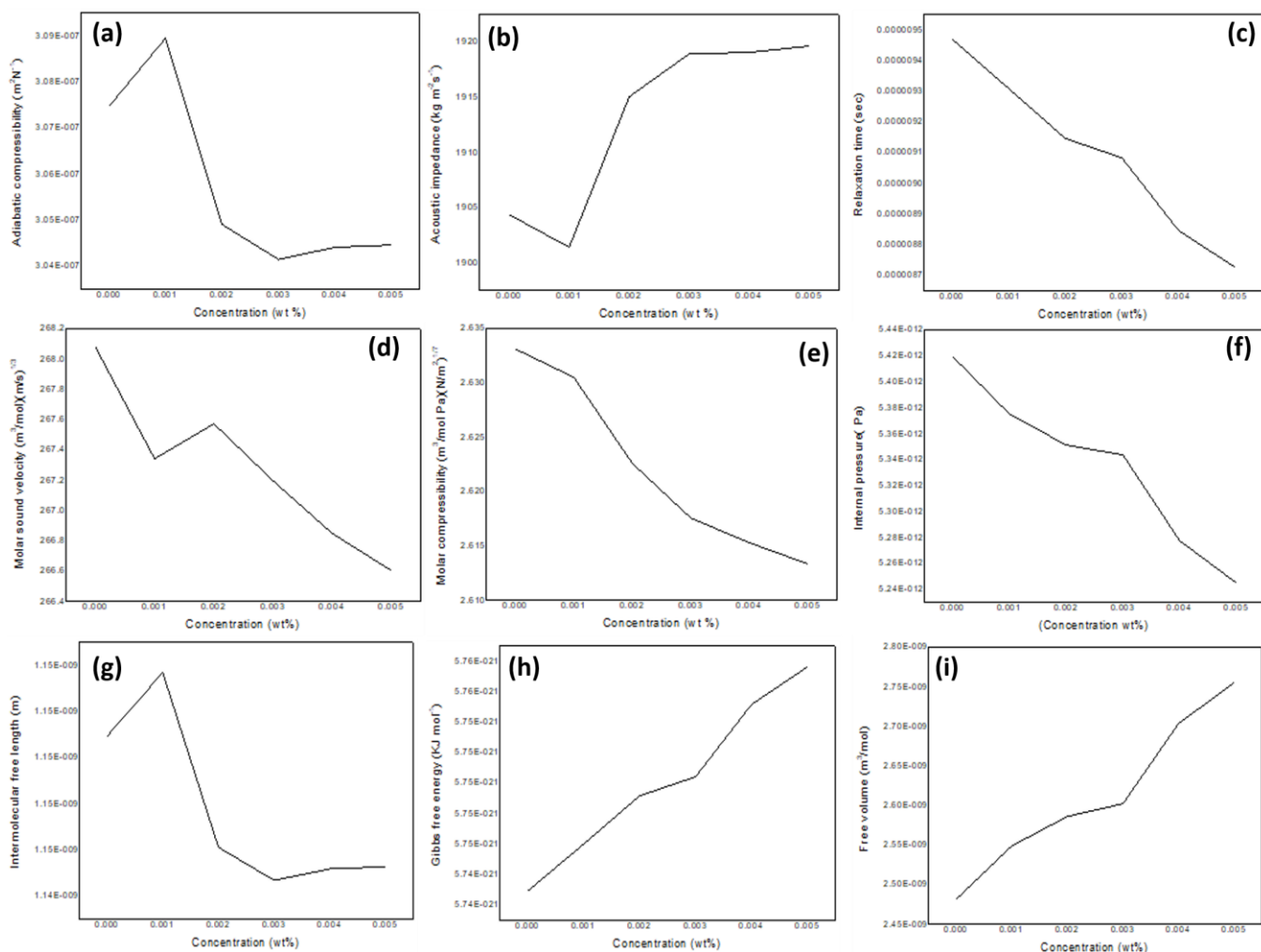
The variation in ultrasonic velocity with concentration is a crucial factor in determining the nanofluids' suitability for applications such as heat transfer. The increase in velocity suggests that the nanofluids become more efficient at transmitting sound waves and energy as nanoparticle concentration rises to an optimal level. This behavior also supports the thermal conductivity findings, as enhanced molecular interactions correspond to improved heat transfer properties. In particular, the concentration of 0.003 g stands out for its superior acoustical properties, indicating that it may be the most effective concentration for practical applications in thermal systems.

By calculating other acoustical parameters, such as adiabatic compressibility, intermolecular free length, and acoustic impedance, further insights into the nanofluids' performance can be gained. These parameters depend on the ultrasonic velocity and density of the fluid, and their variation with concentration provides a deeper understanding of how nanoparticle dispersion affects the overall behavior of the nanofluid. The ultrasonic velocity studies confirm that nanoparticle concentration plays a vital role in influencing the physical properties of BeO glycol nanofluids. The results suggest that the proper tuning of nanoparticle concentration can optimize both acoustical and thermal properties, making these nanofluids valuable for applications requiring efficient heat transfer and energy transmission.

### 3.6. Stability and Zeta Potential Measurements

Stability is a crucial factor in the application of nanofluids, as nanoparticle agglomeration can severely impact the performance of the fluid over time. The stability of the BeO

nanofluids was evaluated using zeta potential measurements, which assess the surface charge of the nanoparticles in the suspension. A higher zeta potential value indicates greater electrostatic repulsion between particles, which prevents agglomeration and ensures long-term stability. Zeta potential measurements for the BeO nanofluids were recorded at various concentrations, and the results are shown in Figure 8. At a concentration of 0.001 wt%, the zeta potential was measured at -38.5 mV, indicating good stability. At higher concentrations, the zeta potential decreases, with the lowest value of -22.3 mV recorded at 0.005 wt%. This reduction in zeta potential suggests that the nanoparticles are more likely to agglomerate at higher concentrations, which aligns with the observed decline in thermal conductivity at these concentrations. The stability of the nanofluids is critical for their practical use, as agglomerated nanoparticles can reduce the fluid's heat transfer properties and increase its viscosity. Therefore, optimizing the concentration of nanoparticles to ensure both high thermal conductivity and stability is essential for the successful application of BeO nanofluids in heat transfer systems.



**Fig. 8.** Acoustical parameters of BeO:diethylene glycol nanofluids.



#### 4. CONCLUSION

In this study, Beryllium Oxide (BeO) nanoparticles were successfully synthesized and characterized using X-ray diffraction (XRD) and scanning electron microscopy (SEM). The XRD analysis confirmed that the synthesized nanoparticles exhibit a hexagonal crystal structure, with an average crystallite size of 22.72 nm. SEM images further validated the uniform morphology and nanoscale dimensions of the BeO particles, showing a well-dispersed and hexagonal-shaped particle distribution. Following synthesis, BeO nanoparticles were dispersed in diethylene glycol to create nanofluids via a two-step method involving sonication. This approach yielded stable suspensions of nanofluids, with concentrations ranging from 0.001 to 0.005 wt%. The thermal conductivity, ultrasonic velocity, and viscosity of the nanofluids were subsequently measured to evaluate their potential for heat transfer applications. The thermal conductivity results revealed that the BeO nanofluids achieved maximum conductivity at a concentration of 0.001 wt%, highlighting this as the optimal concentration for enhanced heat transfer performance. This enhancement is attributed to the nanoparticles' ability to create efficient thermal pathways within the fluid, thus improving heat conduction. Viscosity measurements demonstrated that the interaction between the BeO nanoparticles and diethylene glycol led to a decrease in viscosity, improving fluid flow properties without compromising thermal performance. The BeO nanofluids synthesized in this study show promising potential for use in heat transfer applications, particularly at the 0.001 wt% concentration. The observed improvements in thermal conductivity, coupled with the favorable viscosity characteristics, indicate that these nanofluids could be valuable in thermal management systems, offering an efficient means of enhancing heat transfer.

#### CONFLICT OF INTEREST

The authors declare that there is no conflict of interests.

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