

## **Research** Article

# An Investigation of the Dielectric Properties of Barium Oxide: Therm500 Nanofluids at Different Temperatures

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The dielectric characteristics of barium oxide: Therm500 nanofluids were investigated at a static frequency in this study. Barium oxide: Therm500 nanofluids are made by dispersing barium oxide nanoparticles in Therm500 (base fluid) using a sonicator. The static dielectric measurements were made with a frequency domain reflectometry (FDR) sensor. At various temperatures, the values of several dielectric properties, including dipole moment ( $\mu$ ), molar polarization (P), excess dielectric constant ( $\varepsilon^{E}$ ), static dielectric constant ( $\varepsilon^{O}$ ), and excess dipole moment ( $\mu^{E}$ ), have been measured for BaO: Therm500 nanofluids. Kirkwood factor and Bruggman factor were also computed and presented. The fluctuations in dielectric properties concerning six distinct combinations including 0.001 grams, 0.002 grams, 0.003 grams, 0.004 grams, 0.005 grams, and 0.006 g of nanofluid systems and four different temperatures such as 300 K, 303 K, 313 K, and 323 K are investigated in terms of intermolecular interactions. At all temperatures, the abovementioned dielectric properties BaO: Therm500 nanofluids are positive-negative variations across the whole combination range suggesting in nanofluids the existence of molecular interactions. Synchronization in both parallel and antiparallel of the dipoles in the fluid's mixture are verified by the Kirkwood factor. The Bruggman factor depicts the divergence from the linear relationship in nanofluids, indicating molecular interactions. Dielectric properties of BaO: Therm500 are being studied to understand better their physical, technical, chemical, industrial, laboratory, biological, and pharmaceutical applications.

#### 1. Introduction

The dielectric constant is a material's ability to increase a condenser's capacitance. The dielectric constant is governed by the molecule's permanent dipole moments and its polarizability in terms of structure. The ease with which the electron density of a molecule can be altered is called polarizability. The dielectric constant rises as the dipole moment and polarizability rise. The formation and composition of complexes in nanofluids containing various numbers of nanoparticle molecules are determined using dielectric measurements [1, 2]. Researchers have been intrigued by the dielectric behaviour of polar and non-polar substances, as well as their combinations, at various combinations and

temperatures. Merely only a few researchers, however, have used dielectric properties to investigate the molecular interactions of nanofluids [3, 4].

Dielectric studies have become increasingly important in understanding the interplay of the components in recent years. The other dipole moment in numerous H-bonded complexes was explained using the polarization effect, charge transfer effect, and proton transfer impact. Poor H-bonding can be caused by poor interaction between electrostatic charges. No chemical approach can detect such low-energy hydrogen bonding. As revealed by Sivakumar and Kumar, even weak interactions can be detected in dielectric investigations [5]. They understood the intermolecular interactions induced by dipole-dipole contact and H-bonding. These investigations allow for the provision of precise data on the fluids and their mixtures' chemical mechanics. Dipole-dipole, H-bondingrams, molecular associations, and dipole-induced dipole contact are some of the molecular interactions between components in particle-fluid mixtures [6]. These interactions lead to variations in the dielectric constant and its optimum behaviour. Excessive dielectric constants serve as a definition for these aberrations. Numerous papers [7–10] provide experimental information on excess dielectric constants, Kirkwood correlation factor, and Bruggman factor for a variety of binary and ternary fluid mixes. Conclusions on how systems deviate from the behaviour of an ideal mixture may be drawn from their study.

The intermolecular interaction found in diverse particlefluid mixes determines the thermophysical properties of nanofluids, such as density [11], dielectric constant [12], and refractive index [13]. The dielectric constant and dipole moment deviate from their ideal behaviour due to these interactions [14]. The well-known method for analyzing molecule interactions in fluids uses physical features such as dielectric factors [15]. Therefore, various dielectric factors relating to the intermolecular and intramolecular connection and rotation with temperature fluctuation must be studied to understand molecules' structural behaviour.

It is well accepted that the thermophysical characteristics of fluid systems, including density, viscosity, dielectric constant, and refractive index, are directly correlated with the molecular interactions found in various binary fluid combinations. We learn crucial information about intermolecular interactions and structure from how these qualities vary with composition [16]. Dielectric parameters, refractive index, and thermodynamic parameters do not vary linearly whenever a particle-fluid solution is produced. The deviation of these parameters from linearity is referred to as excess parameters. It helps understand the nature of particle and fluid bonding [2]. Dielectric fluids' properties and physical processes have lately sparked a rush of interest [17]. The underlying difficulties are volume-induced particle contacts and actions in fluids, connected with the dielectric features of these fluids.

The dielectric constant is known as a feature of solvent systems utilized to characterize the electrical components of materials [17]. Excess thermodynamic characteristics have become popular in the study of chemical thermodynamics. Thus, physicists and electrical engineers rarely employ them. As a result, we are looking for a spot in the region of binary dielectrics where excess dielectric permittivity can exist. Fundamental information about molecular interactions and molecular process mechanisms can be gleaned from the frequency-dependent dielectric behaviour of fluid mixtures. For example, the dielectric constant of mixed solvents is necessary for pharmaceutical and analytical sciences to forecast a drug's solubility and chemical stability [18, 19].

Therm500 is an H-bond fluid with a vital dipole moment. Research [20–22] on several binary liquid systems' dielectric and excess dielectric characteristics is essential in chemical and electrochemical operations. Therm500 dielectric constant enables exact conductometry and potentiodynamic polarization measurements [23]. Glycols have lower boiling points than non-polar molecules of the same molecular weight and more incredible boiling points than hydrocarbons of identical mass. Glycols interact more strongly with electron-withdrawing groups in a component than with other molecules. Glycols are bioorganic solvents that are among the essential reagents in organic synthesis. The dielectric constant of mixed solvents nanofluids containing amines is being investigated to understand better its biological, chemical, pharmacological, technical, and laboratory uses [24].

The present study of BaO: Therm500 nanofluids were generated by ultrasonic dispersion. The two-step process is often used to prepare nanofluids and is the most cost-effective way to produce nanofluids on a big scale. The twostep methodology is used in the current work. This procedure involved dispersing pure, synthesized BaO nanoparticles in base fluids (Therm500). Simple mixing is ineffective in producing stable nanofluids, which is the main issue in the formulation of these fluids. Hence, an ultrasonic processor is used in the current work to achieve that goal. This strategy for increasing reaction rate has become a standard synthetic technique for many homogeneous and heterogeneous chemical processes [25]. Their ultrasonic and several dielectric properties such as dipole moment  $(\mu)$ , molar polarization (P), excess dielectric constant ( $\varepsilon^{E}$ ), static dielectric constant ( $\varepsilon^{O}$ ), excess dipole moment ( $\mu^{E}$ ), Kirkwood factor, and Bruggman factor were measured with aid of particle volume (0.001-0.006 g) and temperature (300-323 K), and molecular interaction was investigated.

#### 2. Experimental Section

2.1. Materials Used. The compounds employed in the research are of evolutional spectroscopic grade and consist of a purity of 99.99%. They were utilized without additional purification. BaO nanoparticles were first produced utilizing an ultrasonic aided chemical precipitation technique [26]. Then BaO: Therm500 nanofluids are made using the following procedure: To achieve uniform BaO nanoparticle dispersion in the Therm500 fluid, first weigh the BaO with an accuracy of 0.1 mg using a digital electronic mass balance (model: AY220, SHIMADZU), then mix the BaO nanoparticles with the weighed Therm500, and finally sonicate the mixture continuously for 30 minutes with a cup horn sonicator. A combination without sonication processing has a less uniform and unstable dispersion than the generated nanofluids with sonication processing. In this research, six different concentrations of the synthesized Bao nanoparticles (0.001 g, 0.002 g, 0.003 g, 0.004 g, 0.005 g, and 0.006 g) were combined with the specified amount of base fluids (Therm500). The suspension of the nanofluids was then improved and made more stable by intense ultrasonication using a cup horn sonicator for 30 minutes at a working frequency of 20 kHz and a 100% output amplitude (Hielscher UP400S). To keep the temperature of the suspension consistent, the sonication was carried out in an ice bath. For dispersing the aggregated nanoparticles, the sonication period is a crucial factor. After conducting multiple experiments, 30 minutes was ultimately chosen for this study's sonication period. In order to prevent nanoparticle agglomeration and to create a well-dispersed, stable solution, ultrasonication was one of the dispersion techniques utilized. Venlub Petro Products (P) Ltd., Chennai, Tamil Nadu, India, provided the base fluid Therm500. "Chemical composition varies across heat transfer fluids and thermal oils. Polyglycol and water-glycol fluids, siliconebased greases, and oils are examples of manufactured goods. They are made up of alkaline organic and inorganic chemicals and are employed in the diluted form at combinations ranging from 3% to 10%. Petroleum or mineral oils, as well as water, make up non-synthetic goods. Synthetic fluids are more expensive than non-synthetic fluids, but they perform better in fire resistance and cooling. Semisynthetic fluids have a cost and heat transfer performance halfway between synthetic and soluble oil fluids. Nonflammable compounds containing carbon, chlorine, and fluorine are chlorofluorocarbons (CFCs). This category includes halogenated fluorocarbon (HFC), halogenated chlorofluorocarbon (HCFC), and perfluorocarbon (PFC) fluids" [27].

A water-bath-based temperature control system was used to maintain a 1°C precision level. The sample cell is enclosed in a heat-insulating container, and water is circulated through it at a constant temperature because of a temperature-controlling mechanism. For cells with fluids as the dielectric medium (Cs), the capacitance of the cell can be expressed as the ratio of its capacitance in the air at a certain temperature to that in fluid (Co).

A dipole metre was used to measure the dielectric properties (Mittal Enterprises, New Delhi). Two stainless steel round discs (25 mm in diameter) make up the dielectric cell. Using specific processes, the faces are painstakingly carved and highly polished. The electricity is routed through a specially designed top with a BNC connector that directly corresponds to the two plates of a capacitor at a distance of around 3 mm. An integrated circuit in the function generator allows it to create high-quality sine waveforms with exceptional precision and stability.

For determining the fluid's static dielectric constants, a sensor was utilized. It is based on the same principle as the FDR method basically. Power provides a 100 MHz frequency signal to the sensor. In order to form an electromagnetic field, the pulse is sent to two stainless steel rods. It is possible to measure the dielectric constant with this method because the field travels quickly through the fluids, leading to consistent voltage output. The average of the five tests was used to calculate the dielectric constant. An accuracy of 5% was achieved in the measurement of the dielectric constant.

Benzene is used for reference liquid. To measure the air capacitance of the cell  $(C_o)$ , the capacitance of benzene  $(C_r)$ , and the capacitance fluid whose dielectric constant must be calculated, the dielectric constant of an unknown fluid (x) may be estimated using the relationship  $(C_x)$ .

$$\varepsilon_X = 1 + \left(\frac{C_o - C_X}{C_o - C_R}\right) (\varepsilon_R - 1), \tag{1}$$

where  $\varepsilon_{x^{-}}$  unknown fluid dielectric constant,  $\varepsilon_{R^{-}}$  reference fluid dielectric constant,  $C_{O^{-}}$  air capacitance,  $C_{X^{-}}$  unknown fluid capacitance, and  $C_{R^{-}}$  reference fluid capacitance.

The reference liquid dielectric constant (benzene = 2.26) is denoted by  $\varepsilon_r$ . As an oscillator, a one-of-a-kind functiongenerating semi-conductor is employed. When the data of the resistor (*R*) and capacitor (*C*) change, the frequency of an oscillation changes. As a result, the oscillator's frequency changes. The oscillator's frequency may be used to compute the cell's capacitance and, as a result, the medium's dielectric constant.

2.2. Stability of Nanofluids, Particle Size, and pH Value. Suspension stability is a critical issue in both scientific study and practical applications. The reasonably long stability of nanofluids and their stability in real-world applications should be prioritized. HFC, HCFC, and PFC were used to increase the stability of BaO: Therm500 nanofluids without adding surfactants in this study. So far, the strategies for improving the stability of nanofluids have only been reported to be stable for a few days or a few months [28]. But, in this study, over the course of a month, it was discovered that the suspensions of BaO: Therm500 were stable, and there was no discernible sedimentation. In the future study, an effective and easy strategy for maintaining the long-term stability of BaO: Therm500 nanofluids will be obtained by modifying the surface characteristics of suspended nanoparticles. It suppresses the formation of nanoparticle clusters to generate a stable and homogeneous suspension by adding various surfactant types. Surfactant effects of thermal conductivity measurements of BaO: Therm500 nanofluids were also investigated. In nanofluids, the particle size of nanoparticles is critical for improving heat conductivity and stability. The pH value of the nanofluids also affects their stability. Therm500 nanofluids' size and pH values can be modified in the future to optimize particle size and pH values for increased BaO [29].

2.3. Dielectric Parameters Measurements of Bao: Therm500 Nanofluids. According to dielectric constant values, the derived dielectric parameters are listed below.

2.4. Excess Dielectric Constant ( $\varepsilon^E$ ).  $\varepsilon^E$  indicates the nature of intermolecular interactions and the strength of fluids [30]. It is defined as follows:

$$\varepsilon^{E} = \varepsilon_{12} - (\varepsilon_1 X_1 + \varepsilon_2 X_2), \qquad (2)$$

where  $\varepsilon_{12}$  is the nanofluid dielectric constant;  $\varepsilon_1$  and  $\varepsilon_2$  are the base fluids and nanoparticles dielectric constants, respectively; and  $X_1$  and  $X_2$  are the molar fractions of base fluids and nanoparticles, respectively.

2.5. Dipole Moment ( $\mu$ ). For calculating  $\mu$  of nanofluids, the Kirkwood factor [31, 32] is also useful. Equation (3) has been used by Kumbharkhane et al. [33–35] to examine the

direction of electric dipoles in fluids. The following is an example of an equation that was employed:

$$\mu^{2} = \frac{27 \, KT M_{2}}{4\pi N_{A} d_{1}} \left( \frac{a_{0} - a_{\infty}}{\left(\varepsilon_{01} + 2\right)^{2}} \right),\tag{3}$$

where  $\mu^2$  is the nanofluid's dipole moment, *K* is the Boltzmann's constant, *T* is the temperature,  $M_2$  is the nanoparticles molecular weight,  $N_A$  is the Avogadro's number,  $d_1$  be the solvent density,  $\varepsilon_{01}$  be the base fluid static dielectric constant, and  $a_0$  and  $a_{\infty}$  are the static dielectric constant and optical dielectric constant, respectively. Deviation from unity in an ideal fluid mixing might imply an interaction between the two fluid components.

2.6. Excess Dipole Moment 
$$(\mu^E)$$
. The expression of  $\mu^E$  is  
 $\mu^E = \mu_m - (\mu_A X_A + \mu_B X_B),$  (4)

where  $\mu_m$  be nanofluid mixtures dipole moment;  $\mu_A$  and  $\mu_B$  are the base fluids dipole moments and nanoparticles dipole moments, respectively; and  $X_A$  and  $X_B$  are the base fluids mole fractions and nanoparticles mole fractions, respectively.

2.7. Molar Polarization  $(P_{12})$ . The molar polarization  $(P_{12})$  of nanofluid mixes had been measured using the Clausius–Mosotti equation that states

$$P_{12} = \left(\frac{\varepsilon - 1}{\varepsilon + 2}\right) \frac{M_1 f_1 + M_2 f_2}{d_{12}},$$
(5)

where  $\varepsilon$  be the nanofluid systems dielectric constant;  $f_1$  and  $f_2$  are the constituent's molar combinations and the nanofluid mixtures molar combinations, respectively;  $M_1$  and  $M_2$  are the base fluids molecular weight and nanoparticles molecular weight, respectively; and  $d_{12}$  is the density of the nanofluid mixtures.

2.8. Static Dielectric Constant ( $\varepsilon^0$ ). As the first proof of molecular interactions in nanofluids, the Bruggman mixing formula [36–40] may be applied. The non-linearity of the Bruggman formula best illustrates how solute-solvent interactions change the effective volume of the solute. The Bruggman mixing formula with a volume proportion of nanoparticles is connected to the dielectric constant (0) of nanofluids, which reveals the interaction between fluids and particles. The Bruggman factor  $f_B$  and V are predicted to have a non-linear connection according to equation (6). In nanofluids, this non-linear relationship reveals molecular interaction [41]. The volume fraction of particles (V) may be connected to static dielectric permittivity ( $\varepsilon_{sm}$ ), nanoparticles ( $\varepsilon_{sA}$ ), and fluids ( $\varepsilon_{sB}$ ), which displays the interaction between fluids and particles in the mixture as follows:

$$f_B = \left(\frac{\varepsilon_{\rm sm} - \varepsilon_{\rm sB}}{\varepsilon_{\rm sA} - \varepsilon_{\rm sB}}\right) \left(\frac{\varepsilon_{\rm sA}}{\varepsilon_{\rm sm}}\right)^{1/3} = 1 - V.$$
(6)

#### 3. Result and Discussion

3.1. Static Dielectric Constant ( $\varepsilon^{0}$ ). Figure 1 depicts the fluctuations in  $\varepsilon^0$  with BaO: Therm500 nanofluid combination at four different temperatures (300 K, 303 K, 313 K, and 323 K). Figure 1 of BaO: Therm500 nanofluids indicates that  $\varepsilon_0$  data vary slightly with a rise in all combinations at all four temperatures (300 K, 303 K, 313 K, and 323 K). The creation of solid contacts in the BaO: Therm500 nanofluid system is responsible for the rise in  $\varepsilon_0$  data at a combination of 0.006 g. The number of molecules of BaO present in the BaO: Therm500 nanofluids generates a good shape for the strong interaction at a combination of 0.006 g of BaO nanoparticles. However, the addition of additional BaO disrupts the favorable structure at higher combinations. Therm500 fluids' dielectric constant rises as a direct function of molecule length [42]. Dipole orientation is caused by molecule rotation and intermolecular motion.

When the temperature and the volume fraction of BaO both rise, the dielectric permittivity falls. The orientation of the permanent dipoles is affected by high thermal motion, resulting in a fast reduction in orientation polarization. The reduction in dielectric permittivity as the volume fraction of BaO nanoparticles increases. It might be attributable to the rise in the number of carbon atoms.

This trend might be explained by a decline in the molar volume of the spinning molecule as the number of dipoles in the nanofluid mixture decreases [43]. Figure 1 shows that the static dielectric constant values of BaO: Therm500 nanofluids rise as the combination of BaO nanoparticles increases. The field and dipole alignment move from parallel to antiparallel as a result of this occurrence [44]. Therm500 and BaO have longer chains, making it difficult for the molecules to rotate. In contrast, the static dielectric constant value of BaO: Therm500 nanofluids rises as all five temperatures rise (300 K, 303 K, 313 K, and 323 K).

3.2. Dipole Moment ( $\mu$ ). The dipole moment of BaO: Therm500 nanofluids is shown in Table 1 for six distinct combinations (0.001 grams, 0.002 grams, 0.003 grams, 0.004 grams, 0.005 grams, and 0.006 g) and four different temperatures (300 K, 303 K, 313 K, and 323 K). Except for a combination of 0.003 grams, there is only a minor variance in the dipole moment values for all combinations and temperatures. The shape, configuration, and interfacial charge of molecular entities all influence their ( $\mu$ ). The variation in ( $\mu$ ) of Bao: Therm500 nanofluids with increasing temperature indicates the presence of the Therm500 interaction, whereas no change in ( $\mu$ ) with temperature rises indicates that lack of BaO: Therm500 nanofluids association.

Figure 1 shows the Kirkwood factor ( $g_{\rm eff}$ ) measurements for various combinations and temperatures of BaO: Therm500 nanofluids examined. At 300 K and over the whole volume fraction range, the  $g_{\rm eff} > 1$  shows that the dipole pairs in the mixture have formed in a parallel orientation. However, the  $g_{\rm eff} < 1$  over the whole volume fraction range at 303 K, 313 K, and 323 K temperatures



FIGURE 1: Variations in static dielectric constant values as a function of BaO: Therm500 nanofluids.

TABLE 1: The variation of the molar polarization ( $P_{12}$ ) and dipole moment ( $\mu$ ) values of BaO: Therm500 nanofluids with different combinations.

Concentration, $X_2$ (g)	P 12	μ (D)						
	300 K		303 K		313 K		323 K	
0.000	27.3813	9.12	28.5621	8.15	29.7451	11.63	31.2314	12.98
0.001	25.7882	9.52	27.4526	8.56	29.6542	11.02	31.6587	12.15
0.002	24.8722	9.26	26.7854	8.99	28.1254	9.67	30.8956	10.01
0.003	35.8715	10.01	37.2614	10.82	39.2659	13.95	41.6985	15.65
0.004	30.115	9.54	32.1452	9.12	34.8952	9.89	36.2561	12.45
0.005	29.7935	9.57	31.6852	9.01	33.6985	9.26	35.2614	10.57
0.006	21.895	10.59	23.2658	10.57	30.6521	9.29	34.2365	10.99

suggests that the dipole pairs in the nanofluids have formed an antiparallel orientation.

The dipole moments of the Bao: Therm500 nanofluids with varying BaO combinations at four distinct temperatures are shown in Table 1. The  $\mu$  grows as the temperature rises from 300 K to 323 K. Also, when the temperature increases, molar volume increases. Then when the temperature rises, the thermal disturbance rises. As the dipole elevation increases, the effective length increases correspondingly. A positive dipole moment shows that polarization interaction is to blame for the higher proclivity of complex development in particle-fluid systems [45, 46].

3.3. Molar Polarization ( $P_{12}$ ). The  $P_{12}$  of BaO: Therm500 with different volumes and temperatures are shown in Table 1. The drop in molar polarization values of BaO: Therm500 nanofluids with increasing BaO: Therm500 combinations is due to the weak contact between the BaO and Therm500 molecules. Similarly, the increase in molar polarization values of BaO: Therm500 nanofluids with increasing BaO: Therm500 combinations is owing to the vital contact between the BaO and Therm500 molecules. The molar polarization values of pure BaO: Therm500 nanofluids fluctuate at all volumes, except at 0.003 grams, which reaches a high value at all four temperatures. The increased  $P_{12}$  value at 0.003 g of BaO: Therm500 is attributed to strong interactions in the BaO: Therm500 system. Polarization variations may be affected by the volumes of the nanofluid system. Because of variations in electron negativity, the electron density is focused on one side of a molecule. As a result, the molecule is polarized, with both partial equal charges [47, 48]. Using dielectric constant values BaO: Therm500, the polarizability may be computed directly. In reality, the interactions between them are determined by the polarizability of the chemical and its combination [49].

3.4. Excess Dielectric Constant ( $\varepsilon^E$ ). The  $\varepsilon^E$  values of BaO: Therm500 nanofluids are shown in Figure 2. The  $\varepsilon^E$  data provides the following information  $\varepsilon^E = 0$  and demonstrates that none of the interaction takes place in nanofluid, as a result of which the mixing behaviour is best.  $\varepsilon^E < 0$  indicates that interaction takes place in nanofluids due to a total number of significant dipoles leading to the nanofluid's dielectric polarization hat is lowered.  $\varepsilon^E > 0$  permits interaction to take place in a system that increases the amount of efficient dipoles involved in nanoparticle fluid dielectric polarization. A measure of the intensity of the H-bond contacts between unlike molecules is the magnitude of the  $\varepsilon^E$ values; greater  $\varepsilon^E$  values, and vice versa, signify stronger H-bond, unlike molecular connectivities. The molar



FIGURE 2: The variation of the excess dielectric constant values of BaO: Therm500 nanofluids.

concentration that relates to the higher values of  $\varepsilon^{E}$  denotes the stable combination [50].

Figure 2 depicts  $\varepsilon^E$  versus BaO combination at four distinct temperatures (300 K–323 K).  $\varepsilon^E$  provides significant information regarding interaction of fluids.  $\varepsilon^{E}$  of BaO: Therm500 nanofluids was calculated using equation (3). The excess dielectric constant values for BaO: Therm500 systems are found to be both positive-negative for all combinations. The  $\varepsilon^{E}$ 's negative value indicates that one of the combination components acts as a structure-breaker. For self-association structures based on H-bonding, some dipoles are aligned anti-parallel. These lower  $\varepsilon^{E}$  of the nanofluids below their ideal mixing values by reducing the total amount of parallel aligned dipoles in the mixture [51]. Negative values of  $(\varepsilon^{E})$ are visible in Figure 2 because the less polar configuration is created, resulting in a decreased macro permittivity. The  $(\varepsilon^{E})$ is positive for a few volumes at 300 K, indicating that ideal interaction. During this temperature range, the net dipole moment rises. It has been obtained from Figure 2 that the other three temperatures had similar variations of  $\varepsilon^{E}$ . It is possible that the overall number of dipoles in the fluid is higher than in pure fluids. The formation of new structures results in a greater macroscopic permittivity [52].

3.5. Excess Dipole Moment ( $\mu^E$ ). The fluctuations in the  $\mu^E$  values of pure BaO: Therm500 nanofluids as a function of volume and temperature are depicted in Figure 3. It is also discovered that  $\mu^E$  values of BaO: Therm500 nanofluids vary barely slightly across all combinations, exception of 0.004 g at all 323 K. At a combination of 0.004 g of BaO, the  $\mu^E$  for the pure BaO: Therm500 nanofluids system is negative, showing that the ionic structure of the pure BaO: Therm500 nanofluids makes no contribution to the overall dipole moment. In order to form an ionic structure, an excess dipole moment is required, which is related to protonation [53]. In BaO: Therm500 nanofluids, there is a departure from



FIGURE 3: The variation of the excess dipole moment values of BaO: Therm500 nanofluids.

the linear relationship, indicating molecular interactions in BaO nanoparticles.

#### 4. Conclusion

At different temperatures (300 K-323 K), the dielectric characteristics of the synthesized BaO: Therm500 nanofluids are calculated (0.001 g-0.006 g). The value of the BaO: Therm500 nanofluid dielectric constant rises with temperature. The Kirkwood factor provides evidence for the dipoles' parallel and antiparallel alignment in the mixture of the fluids. At different fluid and nanoparticle combinations at four different temperatures, it seems that the alignment of the dipoles along the field is changing from parallel to antiparallel. The excess permittivity is positive at lower temperatures, meaning there are more dipoles overall in the fluids than there would be if they were pure fluids, which would be the case if the excess permittivity were negative. The excess permittivity turns negative at higher temperatures, suggesting that specific interactions between different molecules are occurring. The ionic structure of the pure BaO: Therm500 nanofluids system does not contribute to the overall dipole moment, as shown by the negative  $\mu^{E}$  for the pure BaO: Therm500 nanofluids system at a combination of 0.004 g of BaO. Negative values of excess dipole moment demonstrate the absence of any contribution to the overall dipole moment from the ionic structure of the BaO: Therm500 nanofluids ( $\mu^E$ ). BaO: Therm500 nanofluids' dielectric characteristics value display positive-negative fluctuations across the combination range at all temperatures, suggesting the presence of intermolecular interactions in nanofluids. BaO: Therm500 nanofluids' molar polarization values change at all volumes, with the exception of 0.003 grams, which experiences a high value at all four temperatures. Strong interactions in the BaO: Therm500 system were said to be the cause of the elevated  $(P_{12})$  value at 0.003 g of BaO. The Bruggman factor exhibits a deviation from the linear relationship in nanofluids, indicating molecular interactions. Ultrasonic and dielectric investigations are used to support the molecular interactions discovered in BaO: Therm500 nanofluids. This paper provides precise dielectric constant values for nanofluids, which are widely used in physical, biological, chemical, industrial, pharmaceutical, technical, and scientific applications.

#### **Data Availability**

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

#### Disclosure

This work was performed as a part of the employment of institutions.

#### **Conflicts of Interest**

The authors declare that there are no conflicts of interest in the article.

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