Chapter

1

Introduction

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1.1 Introduction

The research area of "molecular interaction study" is a very curious topic in molecular biology, physics, and chemistry. This studies how molecules interact through attractive or repulsive forces, whether they are of the same or different types. These interactions are essential in many fields, including materials science, drug development, sensors, protein folding, and nanotechnology. Interactions occur in solids, liquids, and gases, with liquid interactions providing valuable insights into molecular behavior due to the balance between molecular forces and thermal motion. These interactions are driven by specific forces, which are classified into long-range and short-range forces. Long-range forces, or weak forces, occur when molecules approach without overlapping electron clouds and include electrostatic induction and dispersion forces, which are non-directional. Short-range forces, also known as chemical or valence forces, arise when molecules are close enough for their electron clouds to overlap and include dipole-dipole interactions, charge transfer, and hydrogen bonding, all of which are directional. Among these, hydrogen bonding is particularly important in molecular interactions as it can significantly influence the physical and chemical properties of liquids.

Studying molecular interactions in mixtures of two liquids (binary liquid mixtures) is crucial for understanding the structure and dynamics of molecules [1]. Such study to reveal key details about chemical and biological processes, including catalysis and reaction pathways [2-4]. Molecular interactions also provide insights into energy transfer in enzymes and phase transitions [4-7]. To examine interactions in liquids, especially in different polar and nonpolar environments, researchers use various spectroscopic techniques, such as NMR, FTIR, Raman spectroscopy, dielectric relaxation spectroscopy (DRS) and infrared spectroscopy [8-17].

Dielectric relaxation spectroscopy (DRS) is one of the most powerful techniques for studying the molecular behavior of liquids in both pure and mixed states. DRS of polar liquids and their binary mixtures has gained significant attention because it provides valuable information about intermolecular and intramolecular interactions, various relaxation processes, dielectric polarization, and electrical conduction. Low-frequency dielectric dispersion studies offer a detailed understanding of charge dynamics and the electrical conduction mechanisms, which are directly related to dielectric polarization strength and molecular structure [18]. To gain a deeper insight into the dielectric and

electrical properties at lower frequencies, complex conductivity, complex modulus, and complex impedance models are often applied [19–28].

In the microwave frequency region, dielectric relaxation spectroscopy (DRS) provides valuable information about dipolar relaxation processes. When conducted at varying temperatures, it allows the determination of different thermodynamic parameters [29–36]. Additionally, DRS is highly effective in studying hydrogen bond (H-bond) interactions, dipolar alignment, and hydrogen bond connectivity [36-39]. This technique is particularly versatile for investigating conducting fluids, offering insights into the structural dynamics of liquid samples. It reveals not only the molecular interactions within the system but also the formation of monomers and multimers [1]. Dielectric parameters, which are dependent on concentration and temperature, can be linked to the formation of aggregated complex structures in mixtures. Broadband DRS involves measuring the complex permittivity spectra (CPS) of materials across a wide frequency range, from 1 Hz to several THz, and provides critical information about molecular and collective dipolar fluctuations, charge transport, and polarization effects [40]. In the range of 1 μHz to 10^7 Hz, electrode polarization (EP) and ionic conduction relaxation mechanisms are commonly observed in most polar liquids. The frequency range of tens of kHz to hundreds of MHz is associated with the real part of complex permittivity (ε'), which corresponds to the static dielectric region (ε_0). In the microwave frequency region (few hundreds of MHz to 300 GHz), dipolar relaxation processes are prominent, as most polar liquids exhibit high orientation polarizations and significant dielectric loss, reflecting various dielectric relaxations (α, β, and γ). Beyond the microwave range, extending to several terahertz (THz), the material shows collective molecular motions, corresponding to energy-level spacings in this region [43]. The study of molecular interactions and the associated physico-chemical properties, such as density (ρ), viscosity (η) and other related parameters in liquid binary mixtures at varying concentrations and temperatures, is crucial for both industrial and academic purposes. This research provides valuable insights into the physico-chemical and thermodynamic behavior of these mixtures, which is essential for designing, modeling, building, and optimizing equipment like condensers, heat transfer devices, distillation columns, and other process systems [44]. A comprehensive understanding of the physico-chemical properties of multicomponent systems is critical for industrial operations, especially in chemical engineering, and plays a key role in developing new

models for engineering applications [45]. Furthermore, this knowledge is dynamic for exploring thermodynamic and transport properties of solutions [46,47]. To better understand molecular interactions, it is essential to examine the physico-chemical properties of liquids, including the formation and disruption of hydrogen bonds, dipole-dipole interactions, and dipole-induced dipole interactions [48]. Additionally, optical and acoustic properties such as the refractive index (n) and ultrasonic speed (U), can provide further insights into the physical nature and intermolecular forces in liquid materials [44].

1.2 Importance of binary liquids mixtures

Studies on the dielectric, physicochemical, and thermodynamic properties of binary liquid mixtures are highly valuable for both theoretical and practical applications. Mixed solvents, with different dielectric constants, are commonly used to study reaction rates, as the choice of solvent can significantly impact how fast or slow a reaction occurs. For example, simply switching solvents or adding co-solvent can change reaction speeds by as much as a million times. Reactions that move slowly in protic solvents, even at high temperatures, can proceed quickly and with higher yields in aprotic solvents at room temperature. Therefore, a deeper understanding of the structure of these solutions and the interactions between their molecules especially in electrolyte systems is essential for improving our knowledge of many chemical, technological, and biological processes in mixed solvent environments [49,50].

1.3 Literature Survey

Dielectric studies of materials give important information about their dielectric properties and molecular interactions, which are crucial for technology. Understanding how a material's dielectric behavior relates to its molecular structure is a key scientific objective. These properties are useful in many fields, including physical and biological sciences, and engineering. Dielectric studies help us learn more about the molecular structure, behavior, and movement in solutions.

The dielectric properties of liquids help us understand their structure and the molecular interactions within them. By measuring the complex dielectric constant (permittivity) at different frequencies, we can determine the relaxation time, which reveals information about the dynamic molecular properties, energy dissipation mechanisms, and both intermolecular and intramolecular movements. The dipole moment of a molecule affects its permittivity, so studying permittivity can be used to measure a

molecule's dipole moment. Experimental studies of this effect provide valuable insights into molecular and intermolecular motions.

Therefore, the study of dielectric properties of liquid material is necessary not only to understand the liquid structure but also to provide technical data for practical uses in electronics. The study is necessary to understand the physical phenomenon, which occurs in dielectrics, when dielectrics are placed in electromagnetic field and the parameters of the dielectric, which quantitatively determine their properties. The molecular rotations and most of the molecular phenomenon [51,52] take place in the time domain of Pico-second. Hence these changes must be studied at microwave frequency range. Furthermore, microwave is a non-ionizing source of signal for most of the components; it does not affect the molecular structure of material under study. Studying the dielectric properties of liquid materials is important not only to understand their structure but also to provide valuable technical data for practical applications in electronics. This study helps us understand the physical phenomena that occur in dielectrics when they are placed in an electromagnetic field, as well as the parameters that quantitatively define their properties. Molecular rotations and other molecular processes typically occur in the picosecond time range, so these changes need to be studied at microwave frequencies. Over the past two decades, many research articles have been published to explore molecular interactions and structure formation in liquid mixtures using dielectric relaxation spectroscopy (DRS) methods. The extensive efforts by the research community to study liquid materials with these techniques focus on the importance of this research in the current scientific landscape. The following is a literature survey on the study of liquid materials using dielectric relaxation spectroscopy, covering areas such as dielectric studies in the lower frequency range, microwave frequency range, and excess dielectric properties. *Kremer* [53] studied dielectric spectroscopy across a frequency range from 10^6 to 10^{12} Hz for various compounds at different temperatures. He noted that while dielectric spectroscopy is a well-established technique, it continues to develop and has significant technological impact with the potential to open up new possibilities in research and applications. *Chaube* and *Rana* [54] studied the dielectric and electric properties of binary mixtures of anisole and several primary alcohols within the frequency range of 20 Hz to 2 MHz. They used various methods of presenting complex permittivity data to investigate the processes influencing the dielectric and electrical properties of polar-polar liquids. *Vankar* and *Rana* [55] investigated electrode polarization and ionic conduction

relaxation in mixtures of 3-bromoanisole and 1-propanol within the frequency range of 20 Hz to 2 MHz, examining different temperatures. They analyzed how variations in the concentration of components in the binary liquid system, along with temperature changes, influenced various relaxation processes. *Sengwa et al.* [56-58] investigated the dielectric and electrical behavior of poly (vinyl pyrrolidone) combined with polar solvents, poly (vinyl alcohol) with poly (vinyl pyrrolidone), and ethylene glycol oligomers in the lower frequency range of 20 Hz to 1 MHz. From this low-frequency study, they identified specific trends and characteristics in the dielectric and electrical properties of these mixtures. Ionic conduction and electrode polarization greatly affect the increase in complex dielectric constant values in solutions at lower frequencies. In impedance plots, two distinct arcs can be observed: the high-frequency arc represents the bulk material effect, while the low-frequency arc indicates surface polarization effects. The electrode polarization relaxation time represents the average time it takes for an ion to move from one electrode to the other, involving the charging and discharging of the double layer capacitance formed at the electrode-dipolar liquid interface. *Sengwa et al*. [59] examined relaxation processes within the static permittivity frequency range and evaluated the Stokes-Einstein-Nernst relation in propylene carbonate. This study is significant for understanding ion dynamics in polar solvents and the ionic conductivity in solvents, particularly relevant to electrochemistry. *Sengwa et al.* [60] investigated how ionic contaminants affect dielectric dispersion and relaxation processes in pure liquid poly (ethylene glycol) within the static permittivity frequency range. *Jadzyn et* al. [61] investigated electric relaxation effects caused by ionic conductivity in dielectric materials. They analyzed relaxation behavior using impedance and electric modulus formalisms, both showing Debye-type relaxation with the same relaxation time, which depends on the values of DC conductivity (σ_{DC}) and static permittivity (ε_0). Their study includes experimental electric spectra for liquid cyclobutanone, recorded in the frequency range from 500 Hz to 5 MHz and at temperatures between 243 and 313 K. *Sengwa et al.* [62] investigated the static dielectric constant and Kirkwood correlation factor for binary mixtures of N-Methylformamide with formamide, N, N-dimethylformamide, and N, N-dimethylacetamide at 303 K. Their findings confirmed strong hydrogen-bond interactions between different amide molecules (NMF–FA, NMF DMF and NMF–DMA) and the formation of 1:1 molecular complex. *Lone et al.* [63] measured the dielectric parameters for mixtures of methanol and ethanol at various concentrations

across a frequency range of 10 MHz to 20 GHz and at different temperatures using time-domain reflectometry. Their findings showed nonlinear changes in dielectric constant and relaxation time with increasing ethanol volume fraction, suggesting that structural formations occur due to intermolecular interactions between methanol and ethanol molecules. *Karunakaran et al.* [64] studied the dielectric relaxation properties and dipole ordering in binary mixtures of low molecular weight polyvinyl alcohol with water, as well as in ternary mixtures of polyvinyl alcohol and water with dimethylsulphoxide, across a frequency range of 10 MHz to 30 GHz. *Deshmukh et al.* [65] investigated dielectric relaxation and hydrogen bonding interactions in solvents using time-domain reflectometry over a frequency range of 10 MHz to 50 GHz. They concluded that dielectric parameters are more influenced by the structural configuration and dipole moment arrangement of the molecules rather than by the polarity index. *Prajapati et al.* [66] investigated molecular interactions in binary mixtures of 1-propanol with N, N-dimethylformamide across various temperatures. Their study revealed the presence of heteromolecular interactions within the system. *Trivedi* and *Rana* [67] measured the static permittivity, refractive index, density, and related properties of binary mixtures of pyridine and 1-propanol at various temperatures. Their observations indicated strong molecular interactions between pyridine and 1-propanol. *Sengwa et al.* [68] investigated the structure and hydrogen bonding in binary mixtures of N, N-dimethylformamide (DMF) with various dipolar aprotic and protic solvents through dielectric characterization. They found that DMF-water interactions resulted in a strong hydrogen bond due to the disruption of water's tetrahedral structure. Additionally, DMF-alcohol mixtures showed a dependence on the number of hydroxyl groups, leading to a stronger structural organization in the alcohols. *Madhu Mohan* [69] studied the thermodynamic, dielectric, and conformational properties of hydrogen-bonded binary liquid mixtures of propan-1-ol with methyl benzoate and ethyl benzoate. The study identified the formation of hydrogen bonds between the −OH group of propan-1-ol and the −CH group of methyl and ethyl benzoate. These findings were confirmed through FT-IR spectra, showing variations in the measured parameters. *Pradhan et al.* [70] published a review article that provides an overview of the various molecular interactions, both inter and intra, in different non-aqueous binary mixtures. These interactions were studied using dielectric, refractive properties, and spectral characteristics.

In Physiochemical studies, refractive index (n) and density (ρ) are considered intensive properties of liquids. The refractive index is defined as the ratio of the sine of the angle of incidence (in a vacuum) to the sine of the angle of refraction within the medium. This ratio also corresponds to the speed of light in a vacuum relative to its speed in the medium. Density, on the other hand, is the mass of a substance per unit volume.

The refractive index (n) is a key property in optical systems that involve refraction. It helps determine the focusing power of lenses and the dispersion in prisms. As a fundamental physical characteristic, refractive index is commonly used to identify substances, check their purity, or measure concentration. It applies to solids, like glass and gemstones, as well as liquids and gases, with its most common use being to assess solute concentration in aqueous solutions. A refractometer measures the refractive index, which, for example, can reveal the sugar content in a sugar solution.

From a theoretical and process engineering perspective, the thermodynamic properties of binary liquid mixtures provide critical insights, derived from experimental density measurements. Solutions formed by different solute-solvent liquids often display unique behaviors, which may yield desirable physicochemical properties. In the chemical process industry, where materials are typically managed in fluid form, understanding the physical, chemical, and thermodynamic properties of fluids is essential. Additionally, excess thermodynamic properties and deviations from ideal behavior in binary liquid mixtures are fundamental for exploring intermolecular interactions. These properties also serve as qualitative indicators to predict the extent of complex formation within mixtures.

Baskaran et al. [71] investigated the thermophysical properties of para-Anisaldehyde (1) and chlorobenzene (2) at temperatures of 303.15, 313.15, and 323.15 K under a pressure of 0.1 MPa. Their findings revealed negative deviations in viscosity, while positive deviations were observed in refractive index, surface tension, and excess volume across the studied temperatures. *Karel et al.* [72] examined the vapor pressures, refractive index at 20.0 °C, and vapor-liquid equilibrium at 101.325 kPa for the methyl tert-butyl ether–methanol system. *Ramon and Joaquim* [73] investigated the polarizabilities of compounds with diverse chemical characteristics. They concluded that elements with high average atomic polarizabilities typically have a large covalent radius and low electronegativity. The observed average atomic polarizability values

align with those obtained from other experimental measurements and theoretical calculations. *Moosavi et al.* [74] reported the densities, viscosities, and refractive indices for binary mixtures of dimethyl carbonate with 1-hexanol and 1-octanol at atmospheric pressure across various temperatures. From the experimental data, they derived different thermodynamic, transport, and optical properties, analyzing these results in relation to specific molecular interactions and the mixing behavior of the components in the mixtures. *Mrad et al.* [75] studied the thermophysical behavior of binary mixtures of N, N-dimethylacetamide with methanol and ethanol. They measured density, speed of sound, refractive index, and viscosity over the entire mole fraction range at different temperatures. *Moosavi et al.* [76] investigated the thermodynamic and transport properties of aqueous alkanediol systems at atmospheric pressure. They used experimental values of density and refractive index at temperatures ranging from 288.15 to 318.15 K in 5 K intervals, as well as viscosity measurements at 293.15, 298.15, and 303.15 K. *Vural et al.* [77] studied the density, refractive index, and excess molar volume of binary mixtures of glycerol with methanol and glycerol with water at temperatures of 298.15 K and 303.15 K. *Sekhar et al.* [78] measured the densities, refractive indices, and speeds of sound for binary mixtures of 2-chloroaniline with 1-butanol and 2-butanol over the entire mole fraction range at temperatures of 303.15, 308.15, 313.15, and 318.15 K under atmospheric pressure. Their study provided insights into the specific hydrogen bonding interactions in both binary mixtures. *Belhadj et al.* [79] studied the density, speed of sound, refractive index, and related derived/excess properties of binary mixtures of furfural with dimethyl sulfoxide, acetonitrile, and sulfolane at different temperatures. The results were analyzed in terms of intermolecular interactions among the components of these systems. *Rana* and *Chaube* [80] studied the relative permittivity, density, viscosity, refractive index, and ultrasonic velocity of the binary mixture of ethylene glycol monophenyl ether and 1-hexanol at different temperatures. *Gilani* and *Ramezani* [81] reported experimental data on relative permittivity, refractive index, and density for several polar binary systems consisting of cyclopentanone (a cyclic ketone) and a series of alkanols ranging from C_2 to C_{10}. The measurements were conducted over the entire composition range at a temperature of 298.15 K and a pressure of 101.3 kPa.

The properties of liquid-liquid mixtures are thermodynamically significant in the study of thermodynamic, acoustic, and transport phenomena. Intermolecular forces in a liquid mixture have a considerable impact on both physical and chemical properties.

Ultrasonic measurements are widely applied in chemical and food processing, material testing, underwater ranging, and cleaning. Such sound velocity measurements have become especially valuable in polymer technology, helping to elucidate polymer-solvent interactions, polymer structure, and behavior. The study of mixing and excess properties remains an increasingly valuable and challenging area in thermodynamics, attracting much interest. As the modern chemical industry seeks more precise and advanced calculation methods, these developments are likely to bring substantial benefits [82-86]. In the chemical industry, viscosity is one of the critical physical properties of fluids required for designing and optimizing industrial processes [87-92]. *Wilson* and *Richardson* [93] reported near-ideal behavior in ultrasonic velocity and compressibility for binary liquid mixtures of benzene and n-butyl alcohol. *Lavanya et al.* [94] examined the density, viscosity, sound speed, and various thermoacoustic parameters for binary mixtures of benzaldehyde with either chlorobenzene or nitrobenzene at temperatures of 303.15 K, 308.15 K, and 313.15 K. *Alam et al.* [95] investigated densities and viscosities of pure and mixed systems of protic polar solvents, including water, methanol, ethanol, and propan-1-ol, across the entire composition range at different temperatures. The observed positive viscosity deviation in water–alcohol mixtures. *Guo et al.* [96] measured densities and viscosities for binary mixtures of triethylene glycol and water as a function of composition at temperatures of 298.15, 303.15, 308.15, 313.15, and 318.15 K. *Aminabhavi and co-author* [97,99] examined intermolecular interactions between anisole and various alkanols by analyzing excess thermodynamic properties derived from measurements of viscosity, density, and ultrasonic velocity across different temperatures and the full composition range. *Balakrishnan et al.* [100] studied the acoustics of a heavy fuel oil and n-heptane system using an ultrasonic interferometer. Their findings indicated interactions between the components of the binary mixture, suggesting hydrogen bond formation and an increase in molecular interactions as the concentration of heavy fuel oil in the n-heptane system increased. *Sha et al.* [101] measured the densities and viscosities of binary mixtures of 1,2-ethanediamine and 1,4-butanediol at temperatures of 293.15, 298.15, 303.15, 308.15, 313.15, and 318.15 K. The density and viscosity data were used to derive additional parameters, including excess molar volumes and dynamic viscosity deviations. These parameters were analyzed to gain insights into the molecular interactions within the system. *Dikio et al.* [102] studied the densities and viscosities of binary liquid mixtures of pyridine with primary alcohols namely methanol, ethanol, n-

propanol, and n-butanol at temperatures 293.15 K, 303.15 K, 313.15 K, and 323.15 K. suggesting possible hydrogen bond formation of the type N···H─O between dissimilar molecules. *Manukonda et al.* [103] reported data on the density, ultrasonic velocity, and viscosity of binary mixtures of N, N-dimethylaniline with 1-alkanols, 2-alkanols, 2-methyl-1-propanol, and 2-methyl-2-propanol at a temperature of 303.15 K. *Umadevi et al.* [104] studied the liquid-liquid interactions in ternary mixtures of methyl benzoate, cyclohexane, and primary alcohols (1-propanol, 1-butanol, 1-pentanol, and 1-hexanol) by measuring the density, viscosity, and ultrasonic speed at temperatures of 303.15, 308.15, and 313.15 K.

1.3 Binary Liquid System Under Investigated

1.3.1 Binary System

- n-Hexanol + N, N-Dimethylformamide (DMF)
- n-Octanol + N, N-Dimethylformamide (DMF)

Investigating the dielectric properties of binary mixtures of polar liquids provides valuable insights into their molecular interactions, structures, and dynamics. These studies offer essential information about the molecular arrangement and composition of solids and liquids when dielectric measurements are conducted across various frequencies and temperatures. Alcohol and amides are of particular interest among protic and aprotic solvents due to their hydrogen bonding ability. Alcohols, being self-associated liquids, form a three-dimensional hydrogen-bond network, allowing them to interact with other chemical groups with polar attractions. This complex behavior has made alcohol a significant subject of research in fields like chemistry and biology [33, 55, 67, 105].

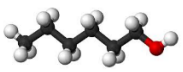
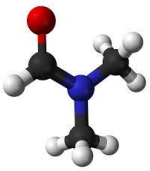
In the chemical industry, amides are important solvents because of their high polarity and strong solvating power. Due to their long-chain molecular structure, alcohols such as n-Hexanol and n-Octanol have widespread applications in industries like petrochemicals, agriculture, and pharmaceuticals [35,106]. In this study, n-Hexanol and n-Octanol are chosen as the alcohol components of the binary liquid system. n-Hexanol, a primary alcohol with a hydroxyl group, forms hydrogen bonds and is ideal for studying molecular interactions in liquid mixtures. It is used in a variety of industries, including petrochemicals, medical (antibacterial agents), agriculture (insecticides), and chemical additives [106]. n-Octanol, a long-chain alcohol, is used in solvents, plasticizer production, and perfumes. It is slightly soluble in water and also forms

hydrogen bonds. Additionally, it plays a role in synthesizing 1-octene, a key compound in polyethylene production and other petrochemical processes [107].

On the other hand, N, N-Dimethylformamide (DMF), an aprotic polar solvent, is selected for this study due to its strong solvating power and high polarity. DMF has significant interest in scientific research, particularly regarding its interactions with peptides and proteins. It is widely used in polymer and pharmaceutical industries [33]. DMF has a large dipole moment and a high dielectric constant, consisting of two hydrophobic -CH_3 groups and one polar C=O group. DMF readily forms hydrogen bonds (C-H…O and C=O…H) with alcohols, enhancing its solvent capabilities and making it a suitable solvent for studying molecular interactions in binary mixtures [108]. Physical and chemical properties of pure liquid (n-Hexanol, n-Octanol and DMF) are tabulated in table 1.1.

Table 1.1 Physical and Chemical Properties of pure liquid.

Property	**Compounds**		
	n-Hexanol	**n-Octanol**	**N, N-Dimethylformamide**
Molecular Formula	$C_6H_{14}O$	$C_8H_{18}O$	C_3H_7NO
IUPAC names	Hexan-1-ol	Octan-1-ol	N, N-Dimethylformamide
Molar Mass	102.17 g/mol	130.23 g/mol	73.09 g/mol
Appearance	Colorless liquid	Colorless to slightly yellow liquid	Colorless liquid
Order	Mild, grassy, fruity	Slightly oily, citrus-like	Faint, fishy/amine-like
Melting Point	−47 °C	−16 °C	−61 °C
Boiling Point	157 °C	195–197 °C	153 °C
Flash Point	59 °C	81 °C	58 °C
Dipole Moment	1.7 D	1.8 D	3.82 D
Dielectric constant	13.05	9.28	37.00
Density (g/cm³)	0.804	0.8254	0.9470

Refractive Index	1.4170	1.4280	1.4305
Ultrasonic Velocity (m/s)	1311.85	1373.09	1493.65
Viscosity (mPa.s)	4.5900	8.7764	0.9200
Molecular Structure			

1.4 Main objectives of the present investigation are as follows

- To study of dielectric and electrical properties of binary mixtures of n-Hexanol+DMF and n-Octanol+DMF at different temperatures (293.15 K →313.15 K) in frequency range 20 Hz to 2 MHz (Using LCR meter).
- To study dielectric properties of binary mixtures of n-Hexanol+DMF and n-Octanol+DMF at different temperatures in frequency range 200 MHz to 20 GHz (Using VNA).
- To study of Acoustical and Physico-chemical properties of the mixtures of n-Hexanol+DMF and n-Octanol+DMF at different temperatures.
- To analyze the dielectric, physicochemical and acoustic parameters to gain information about the solute-solvent interactions and molecular structures.
- Various empirical/semi-empirical mixing models for static dielectric constant, refractive index, ultrasonic velocity and viscosity are tested and validated for the studied binary mixture systems.

References.

[1] S. C. Mehrotra, A. C. Kumbharkhane, A. Chaudhari, Binary polar liquids: structural and dynamic characterization using spectroscopic methods, Elsevier, (2017).

[2] M. B. J. Roeffaers, G. De Cremer, H. Uji-i, B. Muls, B. F. Sels, P. A. Jacobs, F. C. De Schryver, D. E. De Vos, J. Hofkens, Single-molecule fluorescence spectroscopy in (bio) catalysis, Proc. Natl. Acad. Sci. 104 (2007) 12603-12609.

[3] Z. Feng, T. Zhang, H. Wang, B. Xu, Supramolecular catalysis and dynamic assemblies for medicine, Chem. Soc. Rev. 46 (2017) 6470-6479.

[4] G. Parthipan, Liquid state dielectric studies on molecular interaction and fluid structure of binary mixture of anisole with some acids, alcohol and amines, Ph.D. Thesis, Alagappa University, (2008).

[5] R. Karan, M. D. Capes, S. DasSarma, Function and biotechnology of extremophilic enzymes in low water activity, Aquat. Biosyst. 8 (2012) 1-15.

[6] S. Boeynaems, S. Alberti, N. L. Fawzi, T. Mittag, M. Polymenidou, F. Rousseau, J. Schymkowitz, J. Shorter, B. Wolozin, L. Van Den Bosch, Protein phase separation: a new phase in cell biology, Trends Cell Biol. 28 (2018) 420-435.

[7] P. Jena, Physics and chemistry of small clusters, Springer Science & Business Media, (2013).

[8] S. A. Ingole, A. R. Deshmukh, R. V. Shinde, A. C. Kumbharkhane, Dielectric relaxation study of aqueous tetraethylene glycol using time domain reflectometry technique in the frequency range 10 MHz to 50 GHz, J. Mol. Liq. 272 (2018) 450-455.

[9] T. Vishwam, S. Shihab, V. R. K. Murthy, H. S. Tiong, S. S. Sastry, Microwave dielectric relaxation spectroscopy study of propylene glycol/ethanol binary mixtures: Temperature dependence, Spectrochim. Acta Part A Mol. Biomol. Spectrosc. 179 (2017) 74-82.

[10] V. A. Rana, D. P. Shah, C. M. Trivedi, Orientational and dielectric behaviour of N, N-dimethylformamide in different non-polar solvents, Indian J. Pure Appl. Phys. 56 (2018) 677-683.

[11] G. Arivazhagan, A. Elangovan, R. Shanmugam, R. Vijayalakshmi, P. P. Kannan, Spectroscopic studies, NBO analysis and dielectric studies on the behaviour of acetone molecules in non-polar solvent environment, Chem. Phys. Lett. 627 (2015) 101-106.

[12] J. Kiefer, S. Wagenfeld, D. Kerle, Chain length effects on the vibrational structure and molecular interactions in the liquid normal alkyl alcohols, Spectrochim. Acta Part A Mol. Biomol. Spectrosc. 189 (2018) 57-65.

[13] V. Manjula, T. V. Prasad, K. Balakrishna, K. C. J. Raju, T. Vishwam, Investigation of temperature dependent dielectric relaxation studies of 1, 4-Butanediol/DMSO binary mixtures at the microwave frequency, J. Mol. Liq. 299 (2020) 112190.

[14] R. K. Chaudhary, R. Kumar, V. S. Rangra, An investigation on molecular dynamics of binary mixtures of N-methylacetamide and tetramethylurea in microwave region, Indian J. Pure Appl. Phys. 56 (2018) 896-901.

[15] F. Li, Z. Men, S. Li, S. Wang, Z. Li, C. Sun, Study of hydrogen bonding in ethanol-water binary solutions by Raman spectroscopy, Spectrochim. Acta Part A Mol. Biomol. Spectrosc. 189 (2018) 621-624.

[16] M. Matsugami, R. Yamamoto, T. Kumai, M. Tanaka, T. Umecky, T. Takamuku, Hydrogen bonding in ethanol–water and trifluoroethanol–water mixtures studied by NMR and molecular dynamics simulation, J. Mol. Liq. 217 (2016) 3-11.

[17] D. Checinska-Majak, A. Bald, R. J. Sengwa, Static permittivities of n-propanol mixtures with ethanol, isomers of propanol, and butanol at temperature (288.15– 308.15) K, J. Mol. Liq. 179 (2013) 72-77.

[18] R. J. Sengwa, S. Choudhary, P. Dhatarwal, Dielectric and electrical behaviour over the static permittivity frequency regime, the refractive indices and viscosities of PC–PEG binary mixtures, J. Mol. Liq. 252 (2018) 339-350.

[19] R. J. Sengwa, S. Choudhary, S. Sankhla, Low frequency dielectric relaxation processes and ionic conductivity of montmorillonite clay nanoparticles colloidal suspension in poly (vinyl pyrrolidone)-ethylene glycol blends, Express Polym. Lett. 2 (2008) 800-809.

[20] V. P. Pawar, S. C. Mehrotra, Dielectric relaxation study of liquids having chloro group with associated liquids. I. Chlorobenzene with methanol, ethanol, and 1-propanol, J. Solution Chem. 31 (2002) 559-576.

[21] H. A. Chaube, Dielectric, Ultrasonic and Physical Properties of Binary Mixtures of Some Associative Polar Molecules, Ph. D. Thesis, Gujarat University, (2016).

[22] D. K. Barot, Dielectric properties of solutions of 1-Butyl-3-Methyl Imidazolium chloride in polar solvents, Ph.D. Thesis, Gujarat University, (2019).

[23] R. J. Sengwa, S. Sankhla, N. Shinyashiki, Dielectric parameters and hydrogen bond interaction study of binary alcohol mixtures, J. Solution Chem. 37 (2008) 137-153.

[24] A. D. Vyas, V. A. Rana, D. H. Gadani, Dielectric properties of mixtures of some rigid polar molecules with some primary alcohols, Indian J. Pure Appl. Phy. 49 (2011) 277-283.

[25] H. A. Chaube, Dielectric, Ultrasonic and Physical Properties of Binary Mixtures of Some Associative Polar Molecules, Ph.D., Gujarat University., (2016).

[26] R. J. Sengwa, P. Dhatarwal, S. Choudhary, Role of preparation methods on the structural and dielectric properties of plasticized polymer blend electrolytes: correlation between ionic conductivity and dielectric parameters, Electrochim. Acta. 142 (2014) 359-370.

[27] V. A. Rana, T. R. Pandit, Dielectric spectroscopic and molecular dynamic study of aqueous solutions of paracetamol, J. Mol. Liq. 290 (2019) 111203.

[28] K. N. Shah, V. A. Rana, Dielectric spectroscopic study of solutions of amino silicone oil in the polar solvent mixtures of methyl ethyl ketone and methyl iso butyl ketone, J. Mol. Liq. 288 (2019) 111078.

[29] A. Chaudhari, P. Khirade, R. Singh, S. N. Helambe, N. K. Narain, S. C. Mehrotra, Temperature dependent dielectric relaxation study of tetrahydrofuran in methanol and ethanol at microwave frequency using time domain technique, J. Mol. Liq. 82 (1999) 245–253.

[30] T. Vishwam, V. R. K. Murthy, Microwave dielectric relaxation studies of hydrogen bonded polar binary mixtures of isobutanol and aniline, J. Mol. Struct. 1035 (2013) 46- 53.

[31] V. A. Rana, T. R. Pandit, Microwave dielectric relaxation spectroscopy of paracetamol and its aqueous solutions, J. Mol. Liq. 314 (2020) 113673.

[32] J. Bao, M. L. Swicord, C. C. Davis, Microwave dielectric characterization of binary mixtures of water, methanol, and ethanol, J. Chem. Phys. 104 (1996) 4441-4450.

[33] A. N. Prajapati, S. P. Patel, V. A. Rana, Study of short range and long range molecular interactions in binary liquid mixtures of N, N-dimethylformamide (DMF) and 1-propanol, J. Mol. Liq.354 (2022) 118832.

[34] H. A. Chaube, V. A. Rana, D. H. Gadani, Dielectric absorption in mixtures of anisole with some primary alcohols at microwave frequency, Philos. Mag. 91 (2011) 4465-4473.

[35] A. N. Prajapati, A. D. Vyas, V. A. Rana, S. P. Bhatnagar, Dielectric relaxation and dispersion studies of mixtures of 1-propanol and benzonitrile in pure liquid state at radio and microwave frequencies, J. Mol. Liq. 151 (2010) 12-16.

[36] H. P. Vankar, V. A. Rana, S. Dey, H. D. Patel, V. K. Jain, Molecular interaction in binary mixtures of 3-Bromoanisole and methanol: A microwave dielectric relaxation spectroscopy and molecular dynamic simulation study, J. Mol. Liq. (2020) 115186.

[37] T. S. Thakur, M. T. Kirchner, D. Blaser, R. Boese, G. R. Desiraju, Nature and strength of C–H···O interactions involving formyl hydrogen atoms: computational and experimental studies of small aldehydes, Phys. Chem. Chem. Phys. 13 (2011) 14076-14091.

[38] O. W. Kgagodi, F. Mbaiwa, Molecular dynamics study of 2, 2′-difurylmethane and n-propanol binary mixture, J. Mol. Liq. 227 (2017) 366-372.

[39] V. V Chaban, Binary mixtures of novel sulfoxides and water: intermolecular structure, dynamic properties, thermodynamics, and cluster analysis, Phys. Chem. Chem. Phys. 20 (2018) 23754-23761.

[40] R. Raihan, M. R. P. Elenchezhian, V. Vadlamudi, Durability of bonded composite systems, in: Durab. Compos. Syst. (2020) 383-401.

[41] R. T. Hitchcock, Radio-frequency and microwave radiation, AIHA, (2004).

[42] S. Tabassum, Microwave dielectric properties in binary mixture of polar liquids using microwave techniques, Ph.D. Thesis, Swami Ramanand Teerth Marathwada University, (2019).

[43] J. F. Federici, D. Gary, R. Barat, Z. H. Michalopoulou, Detection of explosives by terahertz imaging, in: Counterterrorist Detect. Tech. Explos.(2007) 323-366.

[44] H. P. Vankar, Dielectric and physico-chemical properties of binary mixtures of 3- Bromoanisole and some associative polar liquids, Ph.D. Thesis, Gujarat University., (2021).

[45] A. Estrada-Baltazar, M.G. Bravo-Sanchez, G.A. Iglesias-Silva, J.F.J. Alvarado, E.O. Castrejon-Gonzalez, M. Ramos-Estrada, Densities and viscosities of binary mixtures of n-decane+ 1-pentanol,+ 1-hexanol,+ 1-heptanol at

temperatures from 293.15 to 363.15 K and atmospheric pressure, Chinese J. Chem. Eng. 23 (2015) 559-571.

[46] E. Vercher, F.J. Llopis, V. González-Alfaro, P.J. Miguel, V. Orchillés, A. Martínez-Andreu, Volumetric properties, viscosities and refractive indices of binary liquid mixtures of tetrafluoroborate-based ionic liquids with methanol at several temperatures, J. Chem. Thermodyn. 90 (2015) 174-184.

[47] Luzar, J. Stefan, Dielectric behaviour of DMSO-water mixtures. A hydrogenbonding model, J. Mol. Liq. 46 (1990) 221-238.

[48] P. S. Nikam, M. C. Jadhav, M. Hasan, Density and viscosity of mixtures of dimethyl sulfoxide+ methanol,+ ethanol,+ propan-1-ol,+ propan-2-ol,+ butan-1-ol,+ 2- methylpropan-1-ol, and+ 2-methylpropan-2-ol at 298.15 K and 303.15 K, J. Chem. Eng. Data. 41 (1996) 1028-1031.

[49] Tidar Anil, Structural studies of polar, nonpolar pure liquids and polar-nonpolar binary mixtures through dielectrics and related techniques, Ph.D. Thesis, Dr. Babasaheb Ambedkar Marathwada University, (2010).

[50] C. Gabriel,S. Gabriel, E. H. Grant, Ben S. J. Halstead and D. Michael P. Mingos, Dielectric parameters relevant to microwave dielectric heating, Che. Soi. Reviews, 27 (1998) 213-223.

[51] C. C. Ku and R. Liepins, Electrical Properties of Polymers, Hanser, Munchan, (1987).

[52] R. Buchner and J. Barthel, Dielectric Relaxation in Solutions, Annu. Rep. Prog. Chem., Sect. C. 91(1994) 71-106.

[53] F. Kremer, Dielectric spectroscopy–yesterday, today and tomorrow, J. Non. Cryst. Solids. 305 (2002) 1-9.

[54] H. A. Chaube, V. A. Rana, Dielectric and Electrical Properties of Binary Mixtures of Anisole and Some Primary Alcohols in the Frequency Range 20 Hz to 2 MHz, in: Adv. Mater. Res., Trans Tech Publ. 665 (2013) 194-201.

[55] H. P. Vankar, V. A. Rana, Electrode polarization and ionic conduction relaxation in mixtures of 3-bromoanisole and 1-propanol in the frequency range of 20 Hz to 2 MHz at different temperatures, J. Mol. Liq. 254 (2018) 216-225.

[56] R. J. Sengwa, S. Sankhla, Dielectric dispersion study of poly (vinyl pyrrolidone)– polar solvent solutions in the frequency range 20 Hz–1 MHz, J. Macromol. Sci. Part B Phys. 46 (2007) 717-747.

[57] R. J. Sengwa, S. Sankhla, Dielectric dispersion study of coexisting phases of aqueous polymeric solution: Poly (vinyl alcohol) + poly (vinyl pyrrolidone) two phase systems, Polymer. 48 (2007) 2737-2744.

[58] R. J. Sengwa, S. Sankhla, Characterization of solvent effect on low-frequency dielectric dispersion and relaxation behaviour of ethylene glycol oligomers, J. Mol. Liq. 141 (2008) 73-93

[59] R. J. Sengwa, S. Choudhary, P. Dhatarwal, Characterization of relaxation processes Chapter 1 Department of Physics, Gujarat University 15 over static permittivity frequency regime and compliance of the Stokes-EinsteinNernst relation in propylene carbonate, J. Mol. Liq. 225 (2017) 42-49.

[60] R. J. Sengwa, S. Choudhary, P. Dhatarwal, Effect of ionic contaminants on dielectric dispersion and relaxation processes over static permittivity frequency region in neat liquid poly (ethylene glycol), J. Mol. Liq. 220 (2016) 1042-1048.

[61] J. Swiergiel, J. Jadzyn, Electric relaxational effects induced by ionic conductivity in dielectric materials, Ind. Eng. Chem. Res. 50 (2011) 11935-11941

[62] R. J. Sengwa, V. Khatri, S. Sankhla, Static dielectric constants and Kirkwood correlation factor of the binary mixtures of N-methylformamide with formamide, N, N-dimethylformamide and N, N-dimethylacetamide, J. Solution Chem. 38 (2009) 763-769.

[63] B. G. Lone, P. B. Undre, S. S. Patil, P. W. Khirade, S. C. Mehrotra, Dielectric study of methanol–ethanol mixtures using TDR method, J. Mol. Liq. 141 (2008) 47-53.

[64] D. J. S. A. Karunakaran, T. Ganesh, M. M. Sylvester, P. Hudge, A.C. Kumbharkhane, Dielectric properties and analysis of H-bonded interaction study in complex systems of binary and ternary mixtures of polyvinyl alcohol with water and DMSO, Fluid Phase Equilib. 382 (2014) 300-306.

[65] A. R. Deshmukh, R. V. Shinde, S.A. Ingole, A.W. Pathan, M.P. Lokhande, A. V Sarode, A.C. Kumbharkhane, Dielectric relaxation and hydrogen bonding interaction of solvents using time domain reflectometry technique from 10 MHz to 50 GHz, Indian J. Pure Appl. Phys.56 (2018) 346-352.

[66] A. N. Prajapati, V. A. Rana, A. D. Vyas, D. H. Gadani, A study of molecular interaction in binary mixtures of 1-Propanol with N, N-Dimethylformamide at

different temperatures, in: Adv. Mater. Res., Trans Tech Publ. 665 (2013) 317-325.

[67] C. M. Trivedi, V.A. Rana, Static permittivity, refractive index, density and related properties of binary mixtures of pyridine and 1-propanol at different temperatures, Indian J. Pure Appl. Phys. 52 (2015) 183-191.

[68] R. J. Sengwa, V. Khatri, S. Sankhla, Structure and hydrogen bonding in binary mixtures of N, N-dimethylformamide with some dipolar aprotic and protic solvents by dielectric characterization, Indian J. Chem. 48 (2009) 512-519.

[69] T. M. Mohan, S. S. Sastry, V. R. K. Murthy, Thermodynamic, dielectric and conformational studies on hydrogen bonded binary mixtures of propan-1-ol with methyl benzoate and ethyl benzoate, J. Solution Chem. 40 (2011) 131-146.

[70] S. Pradhan, S. Mishra, An eye on molecular interaction studies of non-aqueous binary liquid mixtures with reference to dielectric, refractive properties and spectral characteristics, J. Mol. Liq. 279 (2019) 317-326.

[71] R. Baskaran, T.R. Kubendran, Thermophysical Properties of para-Anisaldehyde (1) + Chlorobenzene (2) at Temperatures of (303.15, 313.15, and 323.15) K and a Pressure of 0.1 MPa, J. Chem. Eng. Data. 53 (2008) 978-982.

[72] K. Aim, M. Ciprian, Vapor pressures, refractive index at 20.0. degree. C, and vapor- Chapter 1 Department of Physics, Gujarat University 17 liquid equilibrium at 101.325 kPa in the methyl tert-butyl ether-methanol system, J. Chem. Eng. Data. 25 (1980) 100-103.

[73] B. Ramon, S. Joaquim, Polarizabilities of Solvents from the Chemical Compositions, J. Chem. Inf. Comput. Sci. 42 (2002) 1154-1163.

[74] M. Moosavi, A. Motahari, A. Vahid, V. Akbar, A.A. Rostami, A. Omrani, Densities, viscosities, and refractive indices of dimethyl carbonate+ 1-hexanol/1-octanol binary mixtures at different temperatures, J. Chem. Eng. Data. 61 (2016) 1981–1991.

[75] S. Mrad, C. Lafuente, M. Hichri, I. Khattech, Density, speed of sound, refractive index, and viscosity of the binary mixtures of N, N-dimethylacetamide with methanol and ethanol, J. Chem. Eng. Data. 61 (2016) 2946-2953.

[76] M. Moosavi, A. A. Rostami, Densities, viscosities, refractive indices, and excess properties of aqueous 1, 2-etanediol, 1, 3-propanediol, 1, 4-butanediol, and 1, 5- pentanediol binary mixtures, J. Chem. Eng. Data. 62 (2017) 156-168.

[77] U. S. Vural, V. Muradoglu, S. Vural, Excess molar volumes, and refractive index of binary mixtures of glycerol+ methanol and glycerol+ water at 298.15 K and 303.15 K, Bull. Chem. Soc. Ethiop. 25 (2011) 111-118.

[78] M. C. Sekhar, T. M. Mohan, T. V. Krishna, A. Venkatesulu, K. S. Kumar, Density, Refractive Index, Speed of Sound and Computational Studies of Intermolecular Interactions in Binary Mixtures of 2-Chloroaniline with Butanols (1-Butanol, 2- Butanol) at T=(303.15–318.15) K, J. Solution Chem. 44 (2015) 237-263.

[79] D. Belhadj, A. Negadi, P. Venkatesu, I. Bahadur, L. Negadi, Density, speed of sound, refractive index and related derived/excess properties of binary mixtures (furfural+ dimethyl sulfoxide),(furfural+ acetonitrile) and (furfural+ sulfolane) at different temperatures, J. Mol. Liq. 330 (2021) 115436.

[80] V. A. Rana, H. A. Chaube, Relative permittivity, density, viscosity, refractive index and ultrasonic velocity of binary mixture of ethylene glycol monophenyl ether and 1-hexanol at different temperatures, J. Mol. Liq. 187 (2013) 66-73.

[81] A. Ghanadzadeh Gilani, S. Ramezani, Permittivities, Refractive Indices, Densities, and Excess Properties for Binary Systems Containing 1-Alkanols and Cyclopentanone, J. Chem. Eng. Data. 63 (2018) 2888-2903.

[82] D. P. Gulwade, M. L. Narwade, K. N. Wadodkar, Ultrasonic behaviour and study of molecular interactions of substituted azole in N, N-dimethylformamide at different temperatures and concentrations Indian J Chem, 43A (2004) 2102.

[83] J. Gałka, L. Suski, P. Tomczyk, V. Vasilescu, Ultrasonic velocity and compressibility of fused bismuth+ bismuth halide solutions, J Chem Thermodyn, 9 (1997) 673-681.

[84] V. Kannappan, R. Santhi, Ultrasonic study of induced dipole-dipole interactions in binary liquid mixtures, Indian J Pure Appl Phys, 43 (2005) 750.

[85] M. F. Bolotnikov, Y. A. Neruchev, Y. F. Melikhov, V. N. Verveyko, M. V. Verveyko, Temperature dependence of the speed of sound, densities, and isentropic compressibilities of hexane+ hexadecane in the range of (293.15 to 373.15) K, J. Chem Eng Data. 50 (2005) 1095-1098.

[86] C. Valles, E. Perez, A. M. Mainar, J. Santafe, M. Dominguez, Excess enthalpy, density, speed of sound, and viscosity for 2-methyltetrahydrofuran+ 1-butanol at (283.15, 298.15, and, 313.15) K, J Chem Eng Data. 51(2006)1105-1109.

[87] B. Gonzalez, A. Dominguez, Viscosity, density, and speed of sound of methylcyclopentane with primary and secondary alcohols at T=(293.15, 298.15, and 303.15) K, J Chem Thermodyn, 38 (2006) 1172-1185.

[88] L. Grunberg, A. H. Nissan, Mixture law for viscosity, Nature, 164 (1949) 799-800.

[89] M. Tamura, M. Kurata, On the viscosity of binary mixture of liquids, Bull Chem Soc Japan, 25 (1952) 32-38.

[90] R. K. Hind, E. McLaughlin, A. R. Ubbelohde, Structure and viscosity of liquids. Camphor+ pyrene mixtures, Trans Faraday Soc, 56 (1960) 328-330.

[91] P. K. Katti, M. Chaudhri, Viscosities of Binary Mixtures of Benzyl Acetate with Dioxane, Aniline, and m-Cresol, J Chem. Eng Data, 9 (1942) 442-443.

[92] E. L. Heric, On the Viscosity of Ternary Mixtures, J Chem Eng Data. 11 (1966) 66-68.

[93] E. B. Wilson Jr, W. T. Richards, The velocity of sound in solutions of benzene and n-butyl alcohol and n-heptane, J Phys Chem, 36 (1932) 1268-1270.

[94] T. G. Lavanya, K. Saravanakumar, R. Baskaran, T.R. Kubendran, Density, viscosity, sound speed, and thermoacoustical parameters of benzaldehyde with chlorobenzene or nitrobenzene at 303.15 K, 308.15 K, and 313.15 K, Int. J. Thermophys. 34 (2013) 1280-1287.

[95] M. S. Alam, B. Ashokkumar, A. M. Siddiq, The density, dynamic viscosity and kinematic viscosity of protic polar solvents (pure and mixed systems) studies: A theoretical insight of thermophysical properties, J. Mol. Liq. 251 (2018) 458-469.

[96] Z. Guo, J. Zhang, T. Zhang, C. Li, Y. Zhang, J. Bai, Liquid viscosities, excess properties, and viscous flow thermodynamics of triethylene glycol+ water mixtures at T=(298.15, 303.15, 308.15, 313.15, and 318.15) K, J. Mol. Liq. 165 (2012) 27-31.

[97] V. Mutalik, L. S. Manjeshwar, M. Sairam, M. Sairam, T. M. Aminabhavi, Thermodynamic interactions in binary mixtures of anisole with ethanol, propan-1-ol, propan-2-ol, butan-1-ol, pentan-1-ol, and 3-methylbutan-1-ol at T= (298.15, 303.15, and 308.15)K, J Chem Thennodyn, 38 (2006) 1620-1628.

[98] T. M. Aminabhavi, K. Beneijee, Density, Viscosity, Refractive Index, and Speed of Sound in Binary Mixtures of 2-Chloroethanol with Alkanols (C1-C6) at 298.15, 303.15, and 308.15 K, J Chem Eng Data. 43 (1998) 509-513.

[99] T. M. Aminabhavi,V. B. Patil, Density, Viscosity, Refractive Index, and Speed of Sound in Binary Mixtures of Ethenylbenzene with N,N-Dimethylacetamide, Tetrahydrofuran, N,N-Dimethylformamide, 1,4-Dioxane, Dimethyl Sulfoxide, Chloroform, Bromoform, and 1-Chloronaphthalene in the Temperature Interval (298.15−308.15) K, J. Chem. Eng. Data. 43 (1998) 497-503.

[100] J. Balakrishnan, V. Balasubramanian, S. Ekambaram, Acoustic study of Heavy fuel oil-n-Heptane system using ultrasonic interferometer, J. Chem. Pharm. Res. 4 (2012) 3837-3848.

[101] F. Sha, T. Zhao, B. Guo, X. Ju, L. Li, J. Zhang, Density, viscosity and spectroscopic studies of the binary system 1,2-ethylenediamine + 1,4-butanediol at T = (293.15 to 318.15) K, J. Mol. Liq. 208 (2015) 373-379.

[102] E. D. Dikio, S.M. Nelana, D.A. Isabirye, E.E. Ebenso, Density, dynamic viscosity and derived properties of binary mixtures of methanol, ethanol, n-propanol, and n-butanol with pyridine at T=(293.15, 303.15, 313.15 and 323.15) K, Int. J. Electrochem. Sci. 7 (2012) 11101-11122.

[103] G. Manukonda, V. Ponneri, S. Kasibhatta, S. Sakamuri, Density, ultrasonic velocity, viscosity and their excess parameters of the binary mixtures of N, Ndimethylaniline+ 1-alkanols (C 3-C 5),+ 2-alkanols (C 3-C 4),+ 2-methyl-1-propanol,+ 2-methyl-2-propanol at 303.15 K, Korean J. Chem. Eng. 30 (2013) 1131-1141.

[104] M. Umadevi, R. Kesavasamy, K. Rathina, R. Mahalakshmi, Studies on liquid–liquid interactions of some ternary mixtures by density, viscosity and ultrasonic speed measurements, J. Mol. Liq. 219 (2016) 820-828.

[105] A. Marchetti, C. Preti, M. Tagliazucchi, L. Tassi, G. Tosi, The N, N-dimethylformamide + ethane-1,2-diol solvent system. Dielectric constant, refractive index, and related properties at various temperatures. J. Chem. Eng. Data 36(4) (1991) 365-368.

[106] H. Yaman, B. Dogan, M. K. Yesilyurt, D. Erol, Application of Higher-Order Alcohols (1-Hexanol-C6 and 1-Heptanol-C7) in a Spark-Ignition Engine: Analysis and Assessment. Arab. J. Sci. Eng. 46(12) (2021) 11937-11961

[107] L. Cai, Y. Uygun, C. Togbe, H. Pitsch, H. Olivier, P. Dagaut, S. M. Sarathy, “An experimental and modeling study of n-octanol combustion”, Proceedings of the Combustion Institute, 35, 419-427, 2015.

[108] R. J. Sengwa, V. Khatri, S. Sankhla, Structure and hydrogen bonding in binary mixtures of N, N-dimethylformamide with some dipolar aprotic and protic solvents by dielectric characterization, Indian J. Chem. 48A, (2009) 512-519.