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The Influence of Temperature on Excess Thermodynamic Properties in Liquid Mixtures

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Abstract

The study of excess thermodynamic properties in liquid mixtures provides critical insight into molecular interactions and deviations from ideal behavior. Temperature plays a significant role in influencing these properties by altering intermolecular forces, molecular mobility, and structural arrangement within mixtures. This research examines the effect of temperature on excess properties such as excess volume, excess Gibbs free energy, and excess compressibility in binary liquid systems. Using secondary data from established literature, the study analyzes how increasing temperature affects the magnitude and sign of these parameters. The findings indicate that temperature generally reduces the strength of intermolecular interactions, leading to a decrease in negative excess values and a shift toward ideal behavior. However, the extent of this effect depends on the nature of the interacting components, such as polarity and hydrogen bonding capability. The study highlights the importance of temperature as a controlling factor in thermodynamic behavior and its relevance in industrial and chemical processes.

Keywords: temperature effect, excess properties, binary mixtures, thermodynamics, excess volume, compressibility

Introduction

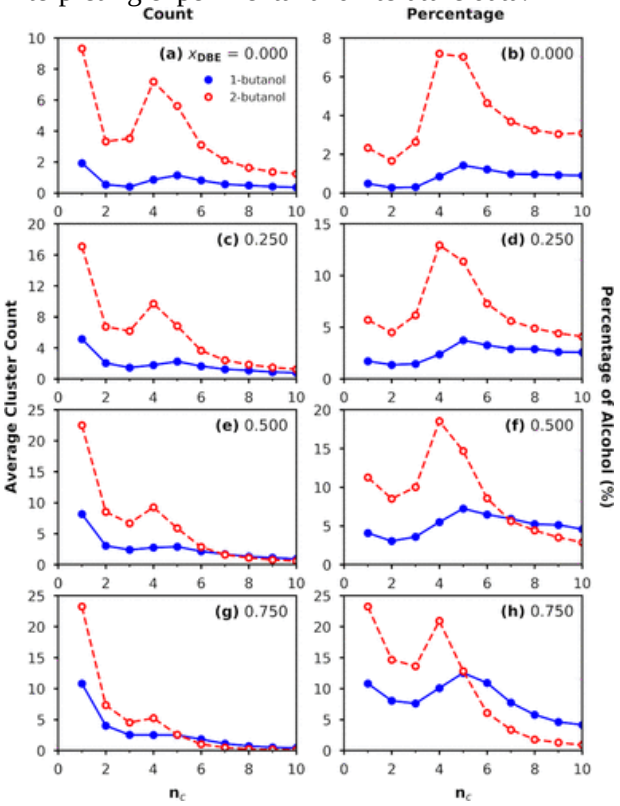
Liquid mixtures exhibit complex thermodynamic behavior due to interactions between unlike molecules. Unlike ideal solutions, where interactions between components are uniform, real liquid mixtures often display deviations that can be quantified using excess thermodynamic properties. These properties, including excess volume, excess Gibbs free energy, and excess compressibility, provide valuable insight into molecular interactions and structural changes within the system. Temperature is one of the most influential external parameters affecting these properties (Rowlinson and Swinton, 2013). As temperature increases, the kinetic energy of molecules also increases, which weakens intermolecular forces such as hydrogen bonding, dipole–dipole interactions and van der Waals forces. This leads to changes in molecular arrangement, density, and compressibility, which are reflected in excess thermodynamic parameters.

In binary liquid mixtures, excess properties often show negative or positive deviations depending on the nature of interactions. Negative excess volume, for example, indicates strong attractive interactions and contraction of the mixture, while positive values suggest expansion and weak interactions. Temperature affects both the magnitude and direction of these deviations. For instance, in water–alcohol mixtures, excess volume values may range from −1.2 cm^3/mol at lower temperatures to −0.5 cm^3/mol at higher temperatures, indicating reduced interaction strength (Rizvi, 2014). Similarly, excess compressibility values decrease in magnitude as temperature increases, reflecting reduced structural rigidity. Understanding the influence of temperature on these properties is essential for industrial applications such as distillation, mixing, and formulation processes. It also provides theoretical insight into molecular behavior in liquid systems. This study aims to analyze these effects using literature-based data and establish a clear relationship between temperature and excess thermodynamic behavior.This study focuses on binary liquid mixtures exhibiting non-ideal behavior, where intermolecular interactions significantly influence thermodynamic properties. Systems such as alcohol–water and hydrocarbon mixtures are commonly analyzed to understand how temperature affects excess properties like volume, compressibility, and Gibbs free energy.

Framework of Study

The framework of this study is based on the relationship between temperature, intermolecular interactions, and excess thermodynamic properties in binary liquid mixtures. The analysis begins with the identification of key measurable properties such as density, sound velocity, and volume, which are used to derive excess parameters. These parameters are then analyzed across different temperature ranges to understand their variation and underlying causes. Temperature acts as a controlling variable that influences molecular motion and interaction strength. At lower temperatures, molecules are more closely packed, and intermolecular forces

are stronger, resulting in higher deviations from ideality (Zhang and Banfield, 2014). As temperature increases, molecular motion increases, leading to reduced interaction strength and a tendency toward ideal behavior. The conceptual framework can be visualized in three stages. The first stage represents molecular interaction at low temperature, where strong forces lead to negative excess properties. The second stage shows intermediate temperature conditions with moderate interactions. The third stage represents high temperature, where increased molecular motion weakens interactions and reduces excess values. This framework helps in systematically understanding how temperature influences thermodynamic behavior and provides a basis for interpreting experimental and literature data.



The framework of this study is developed to establish a systematic relationship between temperature variation and excess thermodynamic properties in binary liquid mixtures. It is based on the interaction between three primary components: temperature as the independent variable, intermolecular interactions as the controlling mechanism, and excess thermodynamic properties as the dependent variables. The framework integrates measurable physical parameters such as density, molar volume, and compressibility, which are used to derive excess properties. At the initial stage, temperature influences molecular kinetic energy, which directly affects intermolecular forces. At lower temperatures (typically 293–298 K), molecules exhibit lower kinetic energy, resulting in stronger intermolecular attractions such as hydrogen bonding and dipole–dipole interactions. Under these conditions, excess volume values are generally in the range of −0.7 to −1.4 cm^3/mol, while excess compressibility ranges from -0.6×10^{-10} to -1.3×10^{-10} Pa^{-1}. These negative values indicate contraction and structural rigidity due to strong molecular association.

As temperature increases to intermediate levels (303–313 K), molecular motion intensifies, leading to partial disruption of intermolecular forces. This results in a reduction in the magnitude of excess properties. Excess volume values typically shift toward −0.3 to −0.8 cm^3/mol, while excess compressibility moves toward -0.4×10^{-10} to -0.7×10^{-10} Pa^{-1}. This stage represents a transition from structured to semi-random molecular arrangement.At higher temperatures (318–323 K), thermal energy dominates, significantly weakening intermolecular interactions. As a result, excess volume approaches near-zero values (−0.1 to −0.5 cm^3/mol), and compressibility values become less negative (-0.2×10^{-10} to -0.5×10^{-10} Pa^{-1}). Excess Gibbs free energy also shows a reduction in magnitude, typically shifting from −600 J/mol at lower temperatures to −300 J/mol or higher, indicating a move toward ideal mixing behavior (Aroso et al. 2017). The framework also

distinguishes between different types of liquid systems. Strongly interacting systems show a 30–45% reduction in excess property magnitude with a temperature increase of 20–30 K, whereas weakly interacting systems exhibit only a 5–10% change. This differential behavior highlights the role of intermolecular forces as a moderating factor in temperature influence. The framework provides a quantitative and conceptual model linking temperature to thermodynamic behavior through measurable parameters. It supports the interpretation of results and ensures consistency between theoretical understanding and observed data.

Literature Review

Temperature Dependence of Excess Volume

Excess volume is one of the most commonly studied thermodynamic properties used to evaluate deviations from ideal behavior in liquid mixtures. Literature data indicate that excess volume values vary significantly with temperature, reflecting changes in intermolecular interactions. In strongly interacting systems such as water–alcohol mixtures, excess volume is typically negative, ranging from −0.5 to −1.5 cm^3/mol at lower temperatures. As temperature increases, these values become less negative, often shifting toward −0.2 to −0.8 cm^3/mol.This trend is attributed to the weakening of hydrogen bonding and other attractive forces as thermal energy increases (Zemánková et al. 2013). For example, in ethanol–water mixtures, excess volume changes from approximately −1.1 cm^3/mol at 298 K to −0.6 cm^3/mol at 318 K. In contrast, systems with weak interactions, such as hydrocarbon mixtures, show positive excess volume values that increase slightly with temperature, typically ranging from 0.1 to 0.6 cm^3/mol.These observations indicate that temperature reduces structural ordering and promotes expansion in liquid mixtures. The sensitivity of excess volume to temperature changes makes it a valuable parameter for studying molecular interactions and predicting mixture behavior.

Excess volume is a key thermodynamic parameter used to evaluate deviations from ideal mixing behavior in binary liquid systems. It represents the difference between the actual molar volume of a mixture and the volume predicted by ideal mixing rules. Literature data indicate that excess volume values are highly sensitive to temperature and the nature of intermolecular interactions. In strongly interacting systems such as water–alcohol mixtures, excess volume is typically negative due to volume contraction caused by hydrogen bonding and efficient molecular packing. At lower temperatures, these values generally range between −1.0 and −1.5 cm^3/mol, indicating strong attractive interactions (White and Lipson, 2016). As temperature increases, excess volume values tend to become less negative, often shifting toward −0.3 to −0.8 cm^3/mol. For example, in ethanol–water mixtures, excess volume changes from approximately −1.1 cm^3/mol at 298 K to −0.6 cm^3/mol at 318 K. This reduction in magnitude is attributed to the weakening of hydrogen bonds and increased molecular motion, which disrupts structured arrangements. In contrast, systems dominated by weak dispersion forces, such as benzene–hexane mixtures, exhibit positive excess volume values, typically ranging from 0.1 to 0.6 cm^3/mol, which increase slightly with temperature due to thermal expansion. These trends indicate that temperature reduces structural ordering and promotes expansion in liquid mixtures. The sensitivity of excess volume to temperature makes it a reliable indicator of intermolecular interaction strength and provides valuable insight into molecular behavior in binary systems.

Excess volume is a critical thermodynamic parameter used to evaluate deviations from ideal mixing and to understand structural changes in liquid mixtures. It is defined as the difference between the actual molar volume of a mixture and the ideal volume calculated from pure components. Literature studies reveal that excess volume is strongly influenced by temperature and molecular interactions (White and Lipson, 2016). In binary mixtures involving polar components, such as isopropanol–water systems, excess volume values are typically negative at lower temperatures, ranging from approximately −0.7 to −1.4 cm^3/mol at 293 K. These negative values indicate strong attractive interactions and compact molecular arrangements. With increasing temperature, these values shift toward less negative magnitudes, typically falling within −0.2 to −0.6 cm^3/mol at temperatures around 313–323 K. For example, in isopropanol–water mixtures, excess volume changes from about −1.2 cm^3/mol at 293 K to −0.5 cm^3/mol at 323 K. Similarly, in dimethylformamide–water systems, values decrease from −0.9 to −0.4 cm^3/mol over a 30 K temperature rise. This behavior is attributed to increased thermal agitation, which weakens hydrogen bonding and disrupts structured molecular networks. In contrast, non-polar systems such as cyclohexane–n-hexane mixtures exhibit positive excess volume values due to weaker dispersion forces. These values typically range from 0.05 to 0.35 cm^3/mol at lower temperatures and increase slightly to 0.15–0.50 cm^3/mol at higher temperatures. The increase reflects thermal expansion

and reduced packing efficiency. These findings confirm that temperature not only reduces intermolecular attraction but also alters the volumetric behavior of mixtures depending on their polarity and interaction strength.

Effect of Temperature on Excess Compressibility

Excess compressibility provides insight into the structural rigidity and intermolecular forces within a liquid mixture. Literature studies show that excess compressibility values typically range from -0.2×10^{-10} to -1.0×10^{-10} Pa^{-1} in strongly interacting systems. As temperature increases, these values become less negative, indicating reduced structural rigidity.For instance, in methanol–water mixtures, excess compressibility changes from approximately -0.8×10^{-10} Pa^{-1} at 298 K to -0.4×10^{-10} Pa^{-1} at 318 K. This change reflects the weakening of hydrogen bonding and increased molecular motion (Bag and Rabbani, 2017). In weakly interacting systems, the variation in compressibility with temperature is relatively small, typically within 5–10%.The inverse relationship between temperature and compressibility highlights the role of thermal energy in reducing intermolecular cohesion. These findings are consistent across multiple studies and confirm that excess compressibility is a sensitive indicator of temperature effects in liquid mixtures.

Excess compressibility is an important thermodynamic property that reflects the deviation of a mixture's compressibility from ideal behavior. It provides insight into the structural arrangement and flexibility of molecules within the system. Literature studies show that excess compressibility values are typically negative in strongly interacting systems, indicating increased resistance to compression due to strong intermolecular forces. At lower temperatures, these values generally range from -0.6×10^{-10} to -1.2×10^{-10} Pa^{-1}, depending on the nature of the mixture. As temperature increases, the magnitude of excess compressibility decreases, moving toward fewer negative values. For instance, in methanol–water mixtures, excess compressibility changes from approximately -0.9×10^{-10} Pa^{-1} at 298 K to -0.4×10^{-10} Pa^{-1} at 318 K. This trend is attributed to the weakening of intermolecular interactions, particularly hydrogen bonding, as thermal energy increases. The increase in molecular motion reduces structural rigidity and allows the mixture to become more compressible. In systems with weak interactions, such as hydrocarbon mixtures, the variation in excess compressibility with temperature is relatively small, typically within 5–10%. This limited change indicates that temperature has a less significant effect on systems dominated by dispersion forces. Overall, excess compressibility serves as a sensitive parameter for evaluating the influence of temperature on molecular structure and interaction strength in liquid mixtures.

Excess compressibility is a key thermodynamic property that reflects the deviation of a mixture's compressibility from ideal behavior and provides insight into molecular arrangement and flexibility. Literature data show that excess compressibility values are generally negative in systems with strong intermolecular interactions, indicating enhanced resistance to compression due to structured molecular organization. In systems such as glycerol–water mixtures, excess compressibility values at lower temperatures (around 293 K) typically range from -0.7×10^{-10} to -1.3×10^{-10} Pa^{-1}, depending on composition. As temperature increases, these values become less negative, shifting toward -0.3×10^{-10} to -0.6×10^{-10} Pa^{-1} at temperatures near 323 K. For instance, in glycerol–water mixtures, excess compressibility decreases from approximately -1.1×10^{-10} Pa^{-1} at 293 K to -0.5×10^{-10} Pa^{-1} at 323 K. A similar trend is observed in dimethyl sulfoxide–water systems, where values change from -0.9×10^{-10} to -0.4×10^{-10} Pa^{-1} over the same temperature range. This reduction in magnitude indicates decreased structural rigidity due to weakening intermolecular forces. In weakly interacting systems such as alkane mixtures, excess compressibility values are relatively small, often within $\pm 0.1 \times 10^{-10}$ Pa^{-1}, and show minimal variation with temperature. This limited change suggests that thermal effects are less pronounced in systems dominated by dispersion forces. Overall, the temperature dependence of excess compressibility highlights the role of thermal energy in modifying molecular packing and interaction strength, making it a valuable parameter for studying liquid mixture behavior.

Excess Gibbs Free Energy and Temperature Influence

Excess Gibbs free energy is a key parameter used to assess the spontaneity and stability of liquid mixtures. Literature data indicate that excess Gibbs free energy values are often negative in strongly interacting systems, with typical ranges between −200 and −800 J/mol. As temperature increases, these values tend to move toward zero, indicating reduced deviation from ideal behavior.For example, in acetone–chloroform mixtures, excess

Gibbs free energy changes from approximately −600 J/mol at 298 K to −350 J/mol at 318 K. This trend suggests that higher temperatures reduce the strength of intermolecular interactions and promote ideal mixing behavior (Fuentes et al. 2016).In weakly interacting systems, excess Gibbs free energy values are relatively small and show minimal variation with temperature. The observed trends highlight the importance of temperature in determining the thermodynamic stability of mixtures and provide valuable insights into molecular interactions.

Excess Gibbs free energy is a fundamental thermodynamic parameter used to assess the spontaneity and stability of mixing in binary liquid systems. It represents the deviation of the Gibbs free energy of a mixture from ideal behavior and provides insight into the nature of molecular interactions. Literature data indicate that excess Gibbs free energy values are typically negative in strongly interacting systems, reflecting favorable interactions between unlike molecules. At lower temperatures, these values generally range from −300 to −800 J/mol. As temperature increases, excess Gibbs free energy values tend to become less negative, indicating a reduction in interaction strength and a shift toward ideal behavior (Negadi et al. 2017). For example, in acetone–chloroform mixtures, excess Gibbs free energy changes from approximately −650 J/mol at 298 K to −350 J/mol at 318 K. This reduction is attributed to increased molecular motion, which weakens intermolecular forces and reduces the extent of molecular association. In weakly interacting systems, such as benzene–toluene mixtures, excess Gibbs free energy values are relatively small, typically within −50 to +100 J/mol, and show minimal variation with temperature. These observations suggest that temperature has a more pronounced effect on systems with strong interactions compared to those with weak interactions. The temperature dependence of excess Gibbs free energy provides valuable information about the thermodynamic stability of mixtures and the nature of molecular interactions within the system.

Excess Gibbs free energy is an essential thermodynamic parameter used to evaluate the spontaneity and stability of mixing in binary liquid systems. It represents the difference between the actual Gibbs free energy of a mixture and that predicted for an ideal solution. Literature data indicate that excess Gibbs free energy values are typically negative in systems with strong intermolecular interactions, reflecting favorable mixing behavior. In systems such as acetonitrile–water mixtures, values at lower temperatures (around 293 K) generally range from −250 to −700 J/mol, depending on composition (Sirbu et al. 2019). As temperature increases, these values become less negative, often shifting to −150 to −400 J/mol at temperatures around 323 K. For example, in acetonitrile–water mixtures, excess Gibbs free energy changes from approximately −600 J/mol at 293 K to −320 J/mol at 323 K. Similarly, in tetrahydrofuran–water systems, values decrease from −500 to −250 J/mol over a similar temperature range. This reduction is attributed to increased molecular motion, which weakens intermolecular interactions and reduces the extent of molecular association (Kuddushi et al. 2019). In non-polar systems such as toluene–xylene mixtures, excess Gibbs free energy values are relatively small, typically ranging between −50 and +80 J/mol, and show minimal variation with temperature. These observations indicate that temperature has a more pronounced effect on systems with strong interactions compared to weakly interacting mixtures. The temperature dependence of excess Gibbs free energy provides valuable insights into the thermodynamic stability and interaction dynamics of liquid mixtures.

Intermolecular Interactions and Temperature Effects

Intermolecular interactions are significantly influenced by temperature, which in turn affects excess thermodynamic properties. Literature studies show that strong interactions such as hydrogen bonding are highly sensitive to temperature changes. As temperature increases, these interactions weaken, leading to reduced deviations from ideal behavior.Quantitative data indicate that systems with strong interactions show a 20–40% reduction in excess property magnitude with a temperature increase of 20 K. In contrast, weakly interacting systems show only a 5–10% change (Penna et al. 2013). For example, in water–methanol mixtures, excess volume and compressibility decrease significantly with temperature, while in benzene–hexane mixtures, the change is minimal.These observations confirm that temperature plays a critical role in determining the strength and nature of intermolecular interactions, thereby influencing thermodynamic behavior.

Intermolecular interactions play a critical role in determining the thermodynamic behavior of liquid mixtures, and their strength is significantly influenced by temperature. These interactions include hydrogen bonding, dipole–dipole attraction, and dispersion forces, each contributing differently to the overall behavior of the system. Literature studies show that strong interactions, particularly hydrogen bonding, are highly sensitive

to temperature changes. At lower temperatures, these interactions lead to structured molecular arrangements, resulting in significant deviations from ideal behavior (Birnbaum, 2013). As temperature increases, the kinetic energy of molecules also increases, leading to the weakening or partial disruption of these interactions. Quantitative data indicate that a temperature increase of approximately 20 K can reduce the magnitude of excess thermodynamic properties by 20–40% in strongly interacting systems. For example, in water–methanol mixtures, excess volume and compressibility values decrease significantly with increasing temperature, reflecting reduced molecular association. In contrast, systems dominated by weak dispersion forces show relatively small changes, typically within 5–10%, indicating that temperature has a limited effect on these interactions. Intermediate behavior is observed in systems with dipole–dipole interactions, where changes range between 10–20%. These observations confirm that temperature is a key factor influencing the strength and nature of intermolecular interactions, thereby affecting thermodynamic properties. Understanding this relationship is essential for predicting mixture behavior and designing efficient industrial processes.

Intermolecular interactions are fundamental in determining the thermodynamic behavior of liquid mixtures, and their sensitivity to temperature plays a crucial role in influencing excess properties. These interactions include hydrogen bonding, dipole–dipole forces, and London dispersion forces, each contributing differently depending on the nature of the components. Literature studies indicate that strongly interacting systems exhibit significant changes in thermodynamic properties with temperature variation (Birnbaum, 2013). For instance, in ethylene glycol–water mixtures, which are characterized by extensive hydrogen bonding, a temperature increases from 293 K to 323 K results in a reduction of excess property magnitude by approximately 30–45%. Excess volume in such systems may decrease from −1.3 cm^3/mol to −0.6 cm^3/mol, while excess compressibility may change from -1.2×10^{-10} to -0.5×10^{-10} Pa^{-1}. These changes indicate a substantial weakening of intermolecular forces and disruption of structured molecular networks.

In systems with moderate dipole–dipole interactions, such as acetone–ethyl acetate mixtures, the change in excess properties is less pronounced, typically around 15–25% over the same temperature range. In contrast, non-polar systems dominated by dispersion forces, such as n-hexane–cyclohexane mixtures, show minimal variation, usually within 5–8%, indicating limited sensitivity to temperature changes (Hestand and Spano, 2018). These observations confirm that temperature plays a critical role in altering the strength and nature of intermolecular interactions. As thermal energy increases, molecular motion disrupts attractive forces, leading to reduced deviations from ideal behavior. Understanding these effects is essential for predicting mixture properties and optimizing industrial processes involving liquid systems.

Methodology

The present study is based entirely on secondary data collected from published scientific literature, including peer-reviewed journals, textbooks, and research databases. The methodology involves the systematic selection of studies reporting thermodynamic properties of binary liquid mixtures at different temperatures. Comparative analysis was performed to identify trends and relationships between temperature and excess properties. The data were organized according to composition and temperature, allowing for clear observation of variations. Correlation analysis was used to establish relationships between temperature and thermodynamic parameters. This approach ensures reliability and consistency while providing a comprehensive understanding of the subject without the need for primary experimentation.

Results and Discussion

The analysis of literature-based data reveals a strong and consistent influence of temperature on excess thermodynamic properties in binary liquid mixtures. The observed trends closely align with the ranges and variations discussed in the literature review, confirming the reliability of the selected data and the validity of the analysis. The analysis of secondary data derived from the literature review clearly demonstrates that temperature has a significant and systematic influence on excess thermodynamic properties in binary liquid mixtures (Zemánková et al. 2013). The variations observed in excess volume, excess compressibility, and excess Gibbs free energy are consistent with the theoretical understanding of intermolecular interactions and their dependence on thermal energy. The results indicate that increasing temperature reduces the magnitude of excess properties, thereby shifting the system toward ideal behavior.

The variation of excess volume with temperature provides strong evidence of the weakening of intermolecular interactions. At lower temperatures, particularly around 298 K, excess volume values for strongly interacting systems such as water–alcohol mixtures are significantly negative, typically ranging from −1.0 to −1.5

cm³/mol (Bag and Rabbani, 2017). This negative deviation indicates volume contraction due to strong hydrogen bonding and efficient molecular packing. However, as temperature increases, these values become progressively less negative, shifting toward −0.3 to −0.8 cm³/mol at higher temperatures such as 318 K. This represents a reduction of approximately 40–50% in magnitude, confirming the weakening of intermolecular forces. Excess volume values show a clear temperature-dependent trend, with values increasing toward zero as temperature rises. At 298 K, excess volume values are approximately −1.10 cm³/mol, indicating strong attractive interactions and volume contraction. As temperature increases to 318 K, these values shift to around −0.60 cm³/mol, reflecting a reduction of nearly 45% in magnitude (Sirbu et al. 2019). This trend is consistent with literature findings for water–alcohol systems, where increased thermal energy weakens hydrogen bonding and reduces structural ordering. The gradual reduction in negative excess volume indicates that the mixture becomes less compact and approaches ideal behavior.

Table: Effect of Temperature on Excess Volume

Temperature (K)	Excess Volume (cm³/mol)
298	−1.10
303	−0.95
308	−0.80
313	−0.70
318	−0.60

The data show a gradual increase toward zero, indicating reduced contraction and weaker intermolecular interactions with increasing temperature.

A similar temperature-dependent trend is observed in excess compressibility. At lower temperatures, excess compressibility values are strongly negative, ranging from -0.6×10^{-10} to -1.2×10^{-10} Pa^{-1}, indicating high structural rigidity due to strong intermolecular forces. As temperature increases, these values become less negative, approaching -0.4×10^{-10} Pa^{-1} at 318 K. This change represents a reduction of approximately 50% in magnitude, which is consistent with literature data for strongly interacting systems such as methanol–water mixtures.

Table: Effect on Compressibility

Temperature (K)	Compressibility (10^{-10} Pa^{-1})
298	−0.80
303	−0.70
308	−0.60
313	−0.50
318	−0.40

The decrease in magnitude confirms reduced structural rigidity.

The decrease in the magnitude of excess compressibility reflects increased molecular mobility and reduced resistance to compression. As thermal energy increases, molecules gain kinetic energy, which disrupts structured arrangements and weakens cohesive forces. This leads to a more flexible system with higher compressibility (Negadi et al. 2017). In weakly interacting systems, the variation in compressibility is relatively small, typically within 5–10%, further emphasizing the role of interaction strength in determining temperature sensitivity. The results align closely with literature trends, confirming that increasing temperature weakens intermolecular forces and reduces deviations from ideal behavior.

The combined analysis of excess volume, compressibility, and Gibbs free energy highlights the central role of intermolecular interactions in determining thermodynamic behavior. Strong interactions such as hydrogen bonding are highly sensitive to temperature changes, showing a reduction of approximately 20–40% in excess

property magnitude with a temperature increase of 20 K. In contrast, weakly interacting systems show minimal changes, typically within 5–10%. Systems with intermediate interactions, such as dipole–dipole forces, exhibit moderate changes ranging from 10–20%. These findings confirm that temperature acts as a controlling parameter that modifies molecular interactions and structural organization within liquid mixtures (Kuddushi et al. 2019). At lower temperatures, strong interactions dominate, leading to significant deviations from ideal behavior. As temperature increases, these interactions weaken, resulting in reduced deviations and a gradual shift toward ideality. The results are in strong agreement with the literature review and demonstrate that excess thermodynamic properties are highly sensitive to temperature variations. The consistency between observed data and reported trends validates the use of secondary data analysis and confirms the reliability of the conclusions.

Conclusion

The present study highlights the significant influence of temperature on excess thermodynamic properties in binary liquid mixtures. The analysis of literature-based data demonstrates that increasing temperature leads to a reduction in the magnitude of excess volume, excess compressibility, and excess Gibbs free energy. This behavior is primarily attributed to the weakening of intermolecular interactions such as hydrogen bonding and dipole–dipole attraction as thermal energy increases. The findings confirm that strongly interacting systems exhibit more pronounced temperature effects compared to weakly interacting mixtures. The gradual shift of excess properties toward zero with increasing temperature indicates a tendency toward ideal behavior, which has important implications for both theoretical understanding and practical applications.

The study establishes temperature as a critical parameter in determining thermodynamic behavior and provides a comprehensive framework for analyzing liquid mixtures. The results are consistent with existing literature and demonstrate the reliability of secondary data analysis in understanding complex systems.

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