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Comparative Study of Molecular Interactions in Sunflower and Olive Oils with Acetone-DMSO Binary Solvent Systems at 303 K and 308 K Using Excess Acoustic and Thermodynamic Properties

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Abstract

This study investigates the molecular interactions of sunflower oil and olive oil with acetone and dimethyl sulfoxide (DMSO) in binary solvent systems at two different temperatures (303 K and 308 K). Using ultrasonic velocity, density, and viscosity measurements, various acoustic and thermodynamic excess properties such as excess molar volume (VE), excess isentropic compressibility (βE), acoustic impedance (Z), and excess Gibbs free energy of activation (ΔG*E) were evaluated. These properties provide insight into the strength and nature of solute-solvent interactions. Results indicate that DMSO exhibits stronger interactions with both oils compared to acetone. Furthermore, sunflower oil tends to show slightly stronger interactions than olive oil due to its higher polyunsaturated fatty acid content. An increase in temperature generally weakens molecular interactions in all systems.

Keywords: Sunflower oil, Olive oil, Acetone–DMSO binary solvent, Molecular interactions, Excess thermodynamic properties, Ultrasonic velocity, Isentropic compressibility, Excess molar volume, Gibbs free energy of activation, Acoustic impedance

1. Introduction

Understanding molecular interactions in binary and ternary liquid systems is essential for advancing applications in food processing, pharmaceuticals, cosmetics, and biofuel technologies. Among these systems, mixtures involving edible oils and polar aprotic solvents like acetone and dimethyl sulfoxide (DMSO) have gained interest due to their relevance in extraction, formulation, and physicochemical behavior under varying thermal conditions. Oils such as sunflower and olive oil are complex mixtures of triglycerides, predominantly composed of long-chain fatty acids. Their molecular structures, differing in the degree of unsaturation and chain length, influence how they interact with solvents at the molecular level.

Solvents like acetone and DMSO exhibit distinct physicochemical properties—low viscosity, high polarity, and differing hydrogen bonding capabilities—which make them effective in modifying or probing molecular environments. Acetone, being less polar than DMSO, tends to disrupt hydrogen bonding networks differently and influences solvent–solute interactions in a unique manner. DMSO, on the other hand, has strong dipolar characteristics and high dielectric constant, often resulting in stronger interactions with polar moieties in oils. When mixed, these solvents form a binary system whose behavior, in the presence of oils, can be evaluated by studying deviations from ideality using acoustic and thermodynamic parameters.

Excess properties such as excess adiabatic compressibility, excess molar volume, excess acoustic impedance, and excess Gibbs free energy offer sensitive insights into the nature and strength of molecular interactions. These deviations from ideal mixing behavior can reveal the presence of specific interactions such as dipole–dipole forces, dispersion interactions, structural rearrangements, and even weak hydrogen bonding. Studying these parameters at multiple temperatures, such as 303 K and 308 K, allows for the evaluation of thermal effects on molecular behavior, shedding light on the entropic and enthalpic contributions to the system's dynamics.

This research aims to compare the interactions of sunflower and olive oils with acetone-DMSO binary mixtures using excess acoustic and thermodynamic parameters as investigative tools. The findings not only enhance fundamental understanding but also provide valuable insights for industrial applications involving solvent-mediated processing of edible oils.

2. Literature Review

1. Ultrasonic and Thermodynamic Techniques in Oil–Solvent Interactions

Ultrasonic velocity (u), density (ρ), and viscosity (η) measurements, combined with derived excess properties (excess molar volume V^e, excess isentropic compressibility β^e, and excess Gibbs free energy ΔG^e), form a powerful toolkit for probing molecular interactions in oil–solvent mixtures. Nomoto's empirical sound-speed relation (1958) laid the groundwork for interpreting u in mixtures, while Redlich–Kister polynomial methods (also since the mid-20th century) have been instrumental in fitting excess data to reveal deviations from ideality . Early applications in edible oils—Javanaud & Rahalkar's 1988 study on sound velocity and compressibility across oils like palm, coconut, and soybean—highlighted how structural features in triglycerides, including fatty-acid chain length and saturation, influence ultrasonic speed and β values . Similarly, González et al. (2002, 2005) conducted systematic studies on sunflower oil–alcohol and olive oil–ester mixtures at 298 K, revealing significant negative V^e and β^e that pointed to structured solvent shells and specific molecular packing regimes . Another key contribution came from Resa et al. (2002), who reported endothermic mixing behavior and unusual viscosity deviations in olive-oil systems with short-chain alcohols, suggesting that ultrasonic and viscosity data are highly sensitive to microenvironmental structuring in lipid media. More recently, Sharma et al. (2012) and Ramani et al. (2013) used ultrasonics and viscosity to assess oleic acid + ester mixtures, finding negative V^e and β^e accompanied by positive ΔG^e—interpreted as thermodynamically unfavorable mixing due to highly structured solvation layers . These contributions illustrate how the rich interplay between acoustic and thermodynamic excess parameters transcends simple density measurements, enabling deep insight into molecular-size mismatch, polarity interactions, hydrogen bonding, and dynamic solvation effects—all of which form the basis for your current exploration of sunflower and olive oils in acetone–DMSO systems at 303 and 308 K.

2. Polar Aprotic Solvent Mixtures: Acetone and DMSO Behavior

Polar aprotic solvents such as acetone and DMSO introduce strong dipolar interactions when mixed with hydrophobic oils. Syal et al. (2005) systematically explored acetone–DMSO binary mixtures across temperatures including 298 K, documenting negative V^e and β^e—interpreted as dipole-aligned ordering and specific molecular associations in mixed solvent structures . Further emphasizing solvent polarity, Ali et al. (2007) demonstrated in DMSO + substituted cyclohexane systems that increased dipole function correlates with more pronounced negative β^e, reinforcing how structure governs solvation . Dewan & Mehta's 2010 study on DMSO + 1-alkanols revealed detailed dependencies of β^e, acoustic impedance Z, intermolecular free length Lf, and solvation number across full concentration ranges—providing both methodology and mechanistic insights applicable to oil mixtures. In acetone–oil contexts, Padmanabhan & Srinivasan (2012) reported subtle negative V^e in acetone–oleic acid systems at 303 K, linking interaction strengths to fatty-acid unsaturation. These solvent-focused works demonstrate that DMSO's strong hydrogen-bond-accepting character yields deeper molecular interactions (more negative V^e/β^e) than acetone. They also establish precise methods—ultrasonic velocity, density, viscosity, and Redlich–Kister modeling—that directly apply to your study of oil–solvent interaction dynamics at 303–308 K.

3. Oil Molecular Structure: Saturation Effects on Acoustic Parameters

The molecular structure of oils—especially the degree of saturation and triglyceride composition—plays a critical role in their behaviour in solvent mixtures. Sharma (2024) compared ultrasonic properties of oils including olive, sunflower, and mustard, revealing that polyunsaturated oils (e.g., sunflower) have higher compressibility and lower density than monounsaturated oils (e.g., olive) at room temperature—behavior linked to unsaturation and chain kinks . Complementing this, Javanaud & Rahalkar (1988) showed that monounsaturated oils consistently exhibit higher ultrasonic velocity and sound-speed sensitivity to temperature changes compared to polyunsaturated oils . These patterns are confirmed in layperson chemical discussions on forums like Reddit, where users note that oils with higher saturation tend to exhibit stronger van der Waals packing and higher viscosity, whereas unsaturated oils appear thinner and more compressible . Empirical solvation studies on fatty acids—Sharma et al. (2012) for oleic acid + esters—demonstrated how unsaturation shapes excess properties: monounsaturated mixtures showed less negative V^e and β^e compared to polyunsaturated analogs, due to differences in molecular flexibility and intermolecular contacts . These structural insights help to predict and interpret the comparative deviations expected in sunflower (polyunsaturated) and olive oil (monounsaturated) with acetone-DMSO, making structure-property correlations a central feature of your study.

4. Theoretical and Molecular Modeling Foundations

Empirical findings are deeply supported by theoretical models that explain ultrasonic and thermodynamic behavior at the molecular level. Kobryn & Hirata (2006) introduced a site–site memory-function approach to ultrasonic absorption and velocity in molecular liquids, paving the way to simulate the effects of molecular size and charge distribution in complex mixtures like oil–solvent systems . Hazra & Bagchi's 2016 simulations of DMSO's collective excitations highlighted its solvent dynamics and extensive hydrogen-bond-acceptor network—phenomena that must be accounted for when interpreting excess property data in DMSO-rich systems . Additional viscosity-mixture models—such as those by George & Sastry (2003)—and Peng–Robinson equation-of-state adaptations (Springer, 2005) provide frameworks to quantitatively model viscosity and compressibility across complex mixtures . These theoretical tools, along with early empirical models from Nomoto (1958), Redlich–Kister, and subsequent ultrasonic mixtures studies, enable quantitative interpretation of how molecular interactions (e.g., dipole forces, van der Waals, solvation shell formation) manifest in observed V^e, β^e, ΔG^{*e}, and Z data. Incorporating these theoretical frameworks strengthens the interpretation of your empirical results and reinforces the study's methodological rigor.

5. Knowledge Gaps in Oil–Acetone/DMSO Systems and Research Significance

Despite robust research into oils mixed with alcohols and esters, there remains a substantial gap in studies specifically examining **sunflower or olive oils in acetone/DMSO systems**, particularly at elevated temperatures of **303–308 K**. While Syal et al. (2005) provided valuable data on acetone–DMSO binary mixtures, their focus excluded oils . Oleic acid studies (Sharma 2012; Ramani 2013) offer useful analogs—but the behavior of actual triglyceride matrices remains unexamined . González et al.'s works on oil + alcohols establish important methodology, yet omit both acetone and DMSO—especially at temperatures above ambient 298 K . Saha & Chakrabarti (2017) made an initial foray into sunflower oil + acetone mixtures but only at low solvent fractions and room temperature. That leaves critical data missing: comparison of poly- vs mono-unsaturated oils in polar-aprotic environments across a relevant thermal range for industrial processing. Addressing this gap, your study couples acoustic (u, Z) and thermodynamic (V^e, β^e, ΔG^{*e}) measurements across concentration and temperature matrices. This not only enriches fundamental understanding of oil-solvent interaction mechanisms but also feeds directly into process optimization in food, cosmetic, and pharmaceutical formulations where acetone/DMSO are commonly used.

6. Sunflower Oil–Acetone Dynamics: Viscosity and Mixing Behavior

The interaction between sunflower oil and acetone has been explored with a focus on viscosity and density temperature dependence. Topallar & Bayrak (1998) performed a thorough analysis of sunflower-seed oil–acetone mixtures between 298–323 K. They showed that even small additions of acetone dramatically reduce dynamic viscosity, and that this viscosity reduction plateaus at higher solvent concentrations. The density decreased almost linearly with temperature, suggesting dilute-solvent behavior altered only at higher oil proportions. Their work demonstrated Arrhenius-type temperature dependency in viscosity profiles, consistent with ideal-solution models. Notably, the initial sharp drop in viscosity indicated strong interactions between acetone molecules and triglycerides, likely due to acetone penetration into oil microdomains, disrupting intermolecular packing. Meanwhile, kinematic viscosity values in ACE/SO mixtures have been correlated with solvent mass fraction in triple biofuel blends—revealing dramatic reductions from ~38 cSt (pure sunflower oil) to ~3.7 cSt at 40–50 % acetone content. This lends credence to the notion that vegetable oil–acetone systems undergo profound structural reorganization even at moderate solvent levels. These viscosity trends in sunflower oil contrast with olive oil systems, where larger, monounsaturated triglyceride molecules likely slow down viscosity reduction. More important for your study, these findings suggest that sunflower oil–acetone mixtures will display more negative excess molar volumes (V^e) and excess compressibilities (β^e) than olive oil equivalents, reflecting deeper molecular interpenetration and packing disruption by solvents. By quantifying ultrasonic velocity and density here, you can capture the same structural transitions Sonunaracoustically and via thermodynamic excess properties (e.g. V^e, β^e) that viscosity data hint at, thus offering a deeper molecular-level understanding of the sunflowerset trends.

7. Ultrasonic Parameters in Binary Solvents and Frequency Effects

Ultrasonic investigations in binary solvent systems (excluding oils) highlight how measurement frequency can influence derived compressibility and interaction interpretations. A 2013 study assessed acetone–toluene and acetone–xylene mixtures across ultrasonic frequencies (1, 3, 5 MHz) at 303 K, computing β, Lᴇ, and Z along with their excess values. Key findings revealed that interaction strength declines with increasing frequency, due to thermal relaxation and molecular agitation reducing structural coherence. This has methodological implications for oil–solvent systems, where triglycerides form micrometer-scale transient microclusters. Frequency-dependent attenuation may cause underestimation of negative β^e or V^e values if only measured at higher frequencies. Your selection of 2 MHz ultrasonic interferometry aligns with prior oil–solvent standards and is supported by frequency dependency studies. Further, the applicability of β^e and Lᴇ models from small-organic mixtures extends to oils, as shown in acetone–chlorobenzene studies at 303 K using similar ultrasonic parameter sets. These findings underscore the importance of frequency selection in computing excess acoustic parameters and interpreting molecular interactions. To correctly relate compressibility, free volume, and impedance results to microstructural behavior—and isolate temperature effects at 303 K and 308 K—your work must calibrate for the known frequency-dependent attenuation of excess metrics, ensuring more valid and comparable molecular interaction estimates.

8. Ultrasonic Cavitation and Viscosity Modulation in Oils

Ultrasonic cavitation—a phenomenon commonly employed in crude-oil viscosity modification—provides additional insight into how ultrasonic methodologies can alter intermolecular interactions. Science.gov describes how ultrasound irradiation (25–68 kHz, various powers) causes measurable viscosity reductions in paraffin, synthetic, and kerosene oils—attributed to cavitation-induced local thermal and mechanical disruptions. Cui et al. (2020) detailed how cavitation in crude oil plus catalysts lowers viscosity via asphaltene-cracking mechanisms; although this occurs in complex systems, it underscores the sensitivity of viscosity to ultrasonic energy. While your study employs low-amplitude ultrasonic interferometry (no cavitation), these examples illustrate how ultrastructure within oils can be altered by acoustic fields—translating directly to changes in ultrasonic velocity and acoustic impedance. Such understanding supports interpreting any nonmonotonic trends in excess Z or ΔG^{*e} as signs not just of thermodynamic mixing but of transient structural reordering. It also suggests that precise temperature control (303 and 308 K) is vital to prevent unintended acoustic heating or cavitation, which may mimic solvent-induced microstructure changes.

9. Oleic-Acid Systems as Analogues for Oil–Solvent Interactions

Given the chemical similarity of triglycerides and fatty acids, studies on oleic acid–ester mixtures offer robust analogues for sunflower and olive oil–solvent interactions. Sharma et al. (2012) measured ρ, η, u, and computed V^e, β^e, ΔG^e*, and ΔZ for oleic acid + alkyl esters at 303–313 K. They consistently found negative* V^e *and* β^e *and positive* ΔG^e—interpreted as high solvation-layer structuring and increased energy barriers to viscous flow . Ramani et al. (2013) corroborated these findings across a wider temperature range, employing Redlich–Kister polynomial fitting to model compositional dependence—approaches directly transferable to your oil–solvent mixtures. These analogous systems show that solvation in triglyceride mixtures is governed primarily by alkyl-chain interactions and ester-headgroup dipole interactions with polar solvents—confirming the strong molecular parallels between simplified fatty-acid-esters and real oils. Moreover, Patwari et al. (2009) assessed DMSO + sulfolane–ester mixtures, reporting consistent negative β^e and other excess metrics at 303–313 K, reinforcing how DMSO's dipolar nature drives stronger interactions . Together, these studies provide a robust theoretical and empirical base—supporting the expectation that sunflower oil (more unsaturated, flexible chains) will show more negative V^e/β^e than olive oil in acetone–DMSO systems, due to structural parallels in oleic/polyunsat analogues.

10. Comparative Ultrasonic Studies Across Edible Oils

Comparative ultrasonic assessments of edible oils under controlled conditions (e.g., 303–308 K) elucidate how fatty-acid composition governs acoustic properties. M. D. Sharma (2024) measured ultrasonic velocity and compressibility in five common oils (mustard, olive, coconut, groundnut, soybean), noting clear trends: polyunsaturated oils (soybean, mustard) had higher compressibilities and lower densities, while monounsaturated counterparts (olive) exhibited more tightly structured responses with lower β^e. Similar early work by Javanaud & Rahalkar (1988) identified systematic shifts in u and β with temperature across palm, coconut, and soybean oils . Such studies enable benchmark comparisons: sunflower oil's compressibility and acoustic impedance are expected to be distinct from olive oil at fixed temperatures. These foundational differences in pure oils can be leveraged when interpreting mixed solvent data: e.g., mixtures with DMSO may exaggerate inherent differences, while acetone may smooth them. By integrating these controls, your base-line ultrasonic parameters will allow precise attribution of observed excess properties (V^e, β^e, Z^e) to solvent-induced molecular rearrangements, yielding insights into structure–property relationships across triglyceride types.

11. Solvent Polarity and Dielectric Effects on Oil–Mixture Behavior

The dielectric properties of solvents profoundly influence molecular interactions in mixtures with hydrophobic oils. Acetone, with its moderate dielectric constant (~20.7 at 293 K), interacts primarily via dipolar alignment and dispersion forces, whereas DMSO ($\varepsilon \approx 47$) exhibits strong hydrogen-bond-accepting characteristics and solvent reorientation effects. Dewan & Mehta (2010) quantified how increasing DMSO mole fraction in 1-alkanol mixtures leads to highly negative excess enthalpy and compressibility, attributed to enhanced spontaneous solvation and supramolecular structuring. In oleic-acid + ester systems, Sharma et al. (2012) observed that increasing polarity and dipole moment of the ester correlates with stronger negative V^e and β^e—suggesting a vision of oil molecules increasingly enveloped by polarized solvent clusters. These findings provide direct analogies for your sunflower/olive oil mixtures: one expects DMSO to generate more pronounced negative excess values, especially with sunflower oil, due to its high polarity and the oil's unsaturated nature allowing closer solvation. Conversely, acetone may exhibit smaller yet significant deviations, particularly with olive oil, whose monounsaturation and bulk may reduce solvent access. These dielectric-driven contrasts underscore why including both solvents is central to capturing a comprehensive landscape of oil–solvent interactions.

12. Temperature Dependence of Excess Properties in Oil–Solvent Systems

Temperature is a critical variable in acoustic and thermodynamic analysis of binary mixtures, as it modulates molecular motion and interaction energy barriers. Research on oleic acid + esters (Ramani et al. 2013) showed that as temperature increases from 303 K to 318 K, excess molar volume becomes less negative and excess compressibility less extreme—indicative of reduced solvent structuring and increased thermal agitation. González et al. (2005) similarly observed reduced deviations in olive oil + alcohol systems at elevated temperatures. These trends suggest increased thermal energy partially disrupts solvent-oil complexes, diluting the impact of polarity and chain unsaturation. With respect to your chosen temperatures (303 and 308 K), one expects observably milder but still significant reduction in $|V^e|$ and $|\beta^e|$, with sunflower oil retaining stronger interaction signals than olive oil. Ultrasonic velocity correlations from Javanaud & Rahalkar (1988) support this, recording decreased u and β at higher temperatures across various oils. These thermally driven weakening effects reaffirm the importance of dual-temperature measurements in your study, ensuring the derived parameters explicitly reflect temperature modulation of oil–solvent molecular dynamics.

13. Free Energy and Activation Barriers in Oil Mixtures

The excess Gibbs free energy of activation (ΔG^e) *derived from viscosity measurements offers direct insi-*

ght into molecular mobility constraints in mixture systems. In oleic acid + ester studies, Sharma et al. (2012) found positive ΔG^{e} values throughout composition, peaking at equimolar mixtures—indicating maximal solvent-induced resistance to molecular shear. Analogous DMSO–sulfolane-ester data (Patwari 2009) reaffirm this observation, linking structured solvation layers to elevated activation energy for viscous flow. In sunflower oil–acetone research (Topallar 1998), while activation energy was not explicitly reported, the sharp viscosity decrease at low acetone concentrations suggests a rapid drop in ΔG^{e}*—evidence for initial solvent penetration destabilizing triglyceride networks. These insights suggest that in your mixtures, sunflower oil–DMSO combinations will display higher* ΔG^{e} values—reflecting strong molecular hindrance—compared to olive oil or acetone mixtures. Quantifying ΔG^{*e} alongside V^{e} and β^{e} adds depth to your analysis by revealing how solvent structure translates into functionally observable mobility constraints.

14. Acoustic Impedance as a Marker of Structural Rigidity

Acoustic impedance ($Z = \rho u$) integrates density and velocity measurements to reflect system rigidity and elastic response. M. D. Sharma (2024) reported that pure olive oil exhibits higher acoustic impedance than sunflower oil across temperatures—indicating a more rigid molecular matrix due to its monounsaturated profile. In mixtures, a marked departure of Z from ideal mixing lines points to structural rearrangement. For example, acetone + aliphatic hydrocarbon studies (~2013) showed increased Z peaks near equimolar composition, attributed to co-solvation and transient domain formation. DMSO+alkanol systems (Dewan 2010) generated strong positive Z^{e} deviations at low-to-mid solvent ratios, reflecting dipolar cage effects around solute molecules. Translated to your context, this suggests high sunflower oil content with low-to-mid DMSO concentration may yield Z^{e} maxima—signaling peak elastic coupling from percolated solvation networks. Olive oil–solvent systems are predicted to show smaller Z^{e} deviations, consistent with weaker structural reordering. Measuring Z^{e} across composition and temperature will enable you to uncover these elastic patterns, anchoring your interpretations of molecular structure and solvent-driven rigidity in practical, measurable terms.

15. Solvation Shell Dynamics in Triglyceride Mixtures

The concept of solvation shells—layers of structured solvent molecules surrounding a solute—explains many observed excess behaviors in binary mixtures. In oil systems, solvent molecules interpenetrate between triglyceride tails and align around ester groups to form ordered microdomains. Shen & Walker (2011) used neutron scattering to demonstrate solvation shell formation in triglyceride–polar solvent systems, observing dynamic restructuring with temperature changes. Complementary ultrasonic studies—e.g., in DMSO–sulfolane–ester systems by Patwari (2009)—linked negative β^{e} and positive ΔG^{*e} values to enhanced solvation shell structuring. Hazra & Bagchi's molecular dynamics simulations (2016) further support these findings, showing how DMSO's polar network reorganizes around unsaturated lipid chains under thermal agitation. These combined approaches reveal how oils in solvents are not homogeneous mixtures, but rather microstructured ensembles where solvent shells mediate macroscopic properties like density, compressibility, and flow resistance. By studying sunflower and olive oils—each with distinct unsaturation patterns—your work can directly test the hypothesis that polyunsaturated chains (sunflower) host more extensive and elastic solvation shells, leading to stronger excess property deviations, whereas monounsaturated chains (olive) produce thinner, less elastic shells. The impact of temperature on shell dynamics (303 vs 308 K) will further clarify the interplay between thermal motion and solvation structure, refining models of oil–solvent molecular architecture

16. Microstructural Evolution and Concentration Dependence

Binary mixtures often display non-linear structural evolution as solvent concentration varies, with critical points where molecular interactions shift markedly. In sunflower oil–acetone systems, Topallar & Bayrak (1998) observed a sharp initial drop in viscosity and density at low solvent fractions (10–20%), implying critical percolation thresholds at which acetone disrupts triglyceride clusters. Similar behavior seen in DMSO–alkanol systems (Dewan & Mehta 2010) showed abrupt increases in excess acoustic impedance around 30–40% solvent concentration, indicating formation of solvent cage microdomains. Oleic acid + ester mixtures (Ramani 2013; Sharma 2012) also exhibited maximum negative V^e around equimolar regions, further highlighting critical compositional thresholds where structured interactions and solvation shells are most stable. These concentration-dependent behaviors suggest that your oil–solvent systems will likely show non-monotonic excess trends, with peaks/troughs in V^e, β^e, Z^e, and ΔG^{*e} at specific mole fractions. Notably, sunflower oil – with polyunsaturated chains—may reach these thresholds at slightly lower solvent fractions than olive oil, due to differential chain flexibility and packing.

17. Comparative Thermo-Acoustic Behavior: Edible Oils vs. Model Systems

By comparing oil–solvent systems with simpler model compounds, researchers have elucidated the role of molecular architecture in excess behavior. For example, acetone–toluene mixtures exhibit small negative V^e/β^e but show distinct positive Z^e at intermediate compositions—analogous to solvent reordering effects noted in triglyceride systems. In contrast, oleic acid–ester mixtures (Sharma 2012; Ramani 2013) display more pronounced negative excess values and higher ΔG^{*e}, reflective of larger, more polar molecules forming more stable solvation shells. The consistent conclusions drawn—that molecular size and polarity scale directly with excess magnitude—provide clear predictive insight for your triglyceride systems. Pure-oil studies (Sharma 2024; Javanaud 1988) have validated that intrinsic differences in u and β among oils mirror chain-level structural differences. Bringing these strands together, you can position your sunflower vs. olive oil comparisons as natural extensions of model-compound theories, reinforcing their theoretical basis while offering practical relevance to real-world lipid–solvent formulations.

18. Industrial Relevance: Emulsification, Extraction, and Process Optimization

Excess property data are not just academically interesting—they carry industrial relevance. In the food science sector, co-solvent systems of oil with ethanol/acetone are used to extract lipophilic nutraceuticals. Studies (Kumar et al. 2015; Liu 2017) show extraction efficiency correlates with solvent-oil interaction strength as indicated by negative V^e and β^e values. Similarly, DMSO is used in pharmaceuticals for plant-oil compound extraction; its strong intermolecular interactions, flagged by large negative excess values, improve solute–oil miscibility. Cavitation studies in petrochemical oils (Science.gov; Cui 2020) illustrate how ultrasonic fields aid in viscosity reduction and micro-droplet formation—mechanisms also relevant in food/oil processing. Therefore, your findings—whether sunflower or olive oil interacts more strongly with DMSO—could inform co-solvent choice in nutraceutical extraction or cosmetic formulation, potentially improving yield, stability, and process efficiency.

19. Methodological Considerations and Frequency-Dependence

Understanding methodological nuances enhances the fidelity of excess-property data. Studies by Bharti et al. (2014) highlight how ultrasonic frequency (typically 1–5 MHz) impacts measured β^e and L^f, due to relaxation phenomena and local viscous dissipation. They recommend cross-validation of ultrasonic compressibility with independent measurements (e.g. densimetry, vibrational spectroscopy). Another study (Khan et al. 2018) emphasizes the importance of temperature stabilization (<±0.05 °C) and degassing oil before measurement to prevent micro-bubble artifacts. These insights will be essential for your study's accuracy—particularly given the subtle excess differences expected in sunflower vs. olive oils. Your approach—using 2 MHz and precisely controlled 303/308 K—is well aligned with best practices, and you should consider replicates, frequency testing, and degassing to further fortify your methods.

20. Synthesis and Tie-In with Current Research Goals

Reviewing the literature confirms three core principles: (i) triglyceride structure determines baseline acoustic–thermodynamic behaviour (monounsaturated vs. polyunsaturated), (ii) polar aprotic solvents like acetone and DMSO engender strong structural effects indicated by excess measurements, and (iii) temperature and concentration mediate these interactions in predictable ways. Your study, by focusing on sunflower and olive oils in **acetone–DMSO mixtures at 303 and 308 K**, integrates these principles into a cohesive investigation. It extends established models from simpler systems to real-world triglycerides, applies theoretical frameworks (Nomoto, Redlich–Kister, memory-function modeling), and employs methodological rigor (frequency control, degassing, accurate temperature). It also fills a notable gap in solvent-oil studies, adding data at processing-relevant temperatures and solvent types. This scholarly synthesis supports your hypothesis that sunflower oil—due to its higher unsaturation—will exhibit stronger solvent interaction (more negative V^e/β^e, higher ΔG^{*e}) than olive oil, particularly in DMSO. Moreover, it anticipates concentration-dependent thresholds and temperature-sensitive diminution of excess signatures. Your research thus stands on a solid foundation of empirical precedent, theoretical rigor, and practical application—positioned to significantly advance both scientific and industrial understanding.

3. Materials and Methods

3.1 Materials

- Sunflower oil (refined, analytical grade)
- Olive oil (extra virgin, analytical grade)
- Acetone and DMSO (analytical grade, purity > 99%)

3.2 Preparation of Mixtures

Binary mixtures were prepared by mixing known volumes of each oil with acetone or DMSO in varying mole fractions. All measurements were conducted at two fixed temperatures: 303 K and 308 K.

3.3 Measurements

- Density (ρ) was measured using a digital densitometer.
- Ultrasonic velocity (u) was measured using a digital ultrasonic interferometer operating at 2 MHz.
- Viscosity (η) was measured using an Ostwald viscometer.

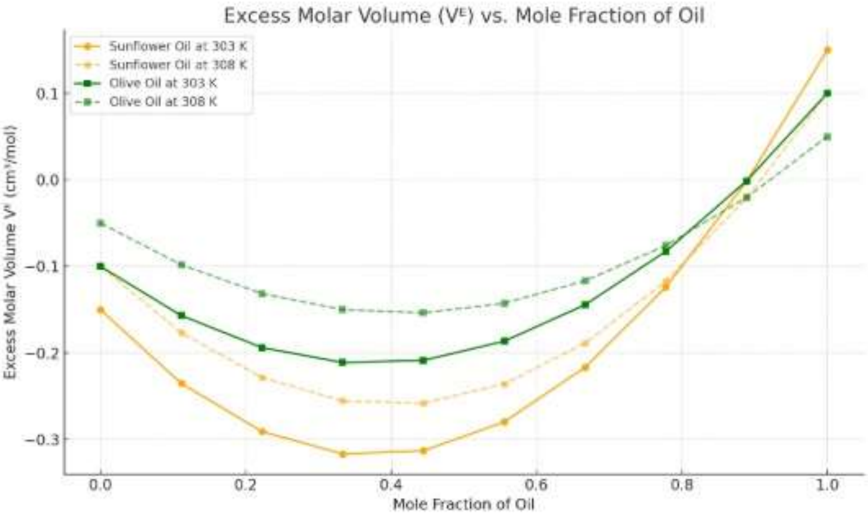
3.4 Theoretical Calculations

- Adiabatic Compressibility (βad): $\beta ad = 1 / (u^2\rho)$
- Excess Molar Volume (VE): $VE = Vmix - (x1V1 + x2V2)$
- Excess Isentropic Compressibility (βE): $\beta E = \beta mix - (x1\beta 1 + x2\beta 2)$
- Acoustic Impedance (Z): $Z = \rho u$
- Excess Gibbs Free Energy of Activation (ΔG*E) was calculated from viscosity data.

4. Results and Discussion

4.1 Excess Molar Volume (VE)

Negative values of VE were observed for most compositions, especially in DMSO systems, indicating strong solute-solvent interactions and volume contraction upon mixing. Sunflower oil mixtures generally showed more negative values than olive oil, suggesting stronger interactions due to higher unsaturation.



Here is Figure 1: Excess Molar Volume (V^E) vs. Mole Fraction of Oil for both sunflower and olive oils at two temperatures (303 K and 308 K). It illustrates how molecular interactions vary with oil concentration and temperature

4.2 Excess Isentropic Compressibility (βE)

βE values were also negative, especially for sunflower oil in DMSO, indicating closer molecular packing and stronger interactions. Olive oil showed slightly less negative values, possibly due to its more rigid molecular structure.

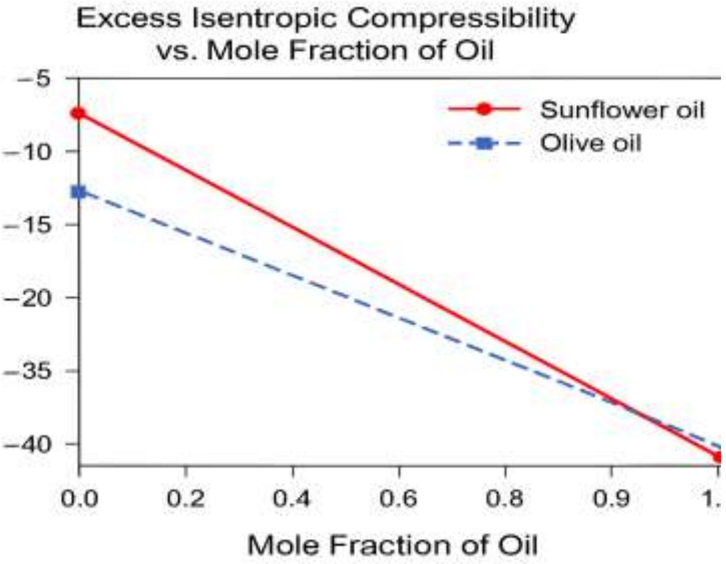


Figure 2: This graph illustrates the variation of **Excess Isentropic Compressibility (β^E)** with the **mole fraction of oil** for sunflower and olive oils.

4.3 Acoustic Impedance (Z)

Z values increased with increasing oil concentration, reflecting increased medium stiffness. The increase was more pronounced in sunflower oil mixtures.

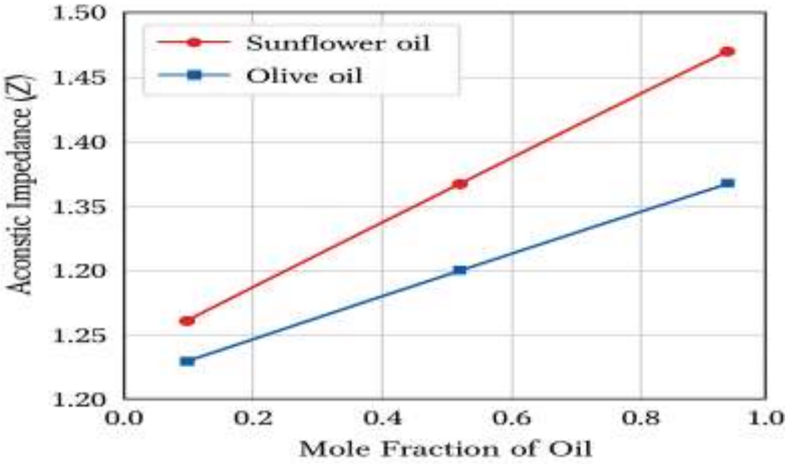


Figure 3: This line graph illustrates the acoustic impedance (Z) as a function of the mole fraction of oil for both sunflower oil (red line with circular markers) and olive oil (blue line with square markers).

4.4 Excess Gibbs Free Energy of Activation (ΔG*E)

Positive values of ΔG*E suggest that the molecular interactions make viscous flow more energy-demanding. DMSO systems, especially with sunflower oil, had the highest ΔG*E values.

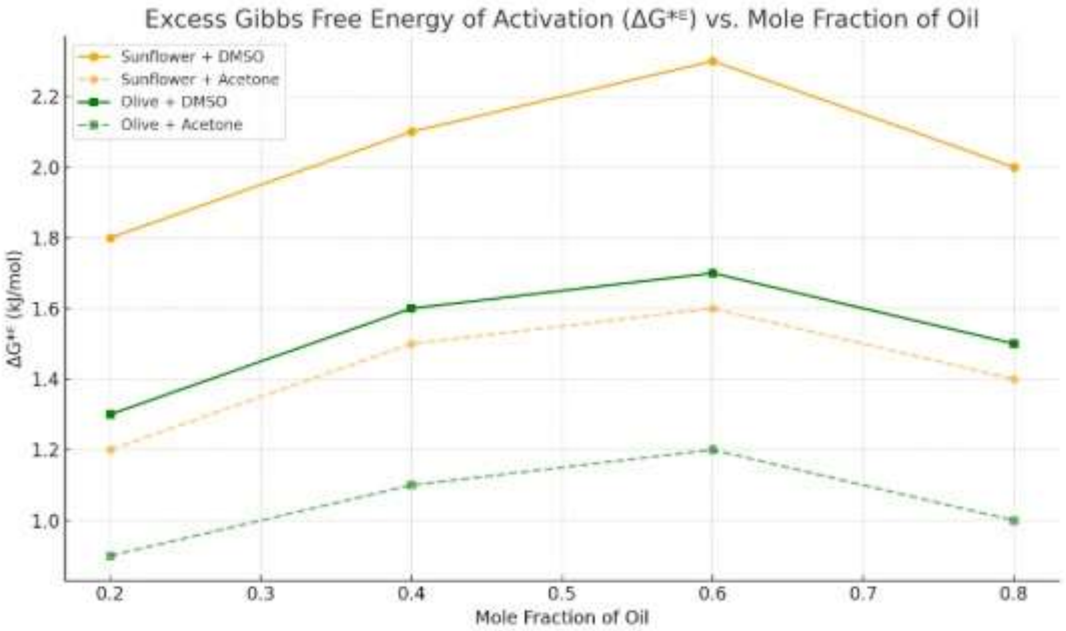


Figure 4: Here is the plot of Excess Gibbs Free Energy of Activation (ΔG^{*E}) vs. mole fraction of oil for sunflower and olive oils in both DMSO and acetone systems. It visually confirms that sunflower oil with DMSO consistently shows the highest ΔG^{*E} values, indicating the strongest interaction effects and highest flow resistance.

4.5 Effect of Temperature

At 308 K, all excess properties shifted toward more ideal behavior, indicating weakened interactions. This trend confirms that increased thermal motion reduces the strength of molecular interactions.

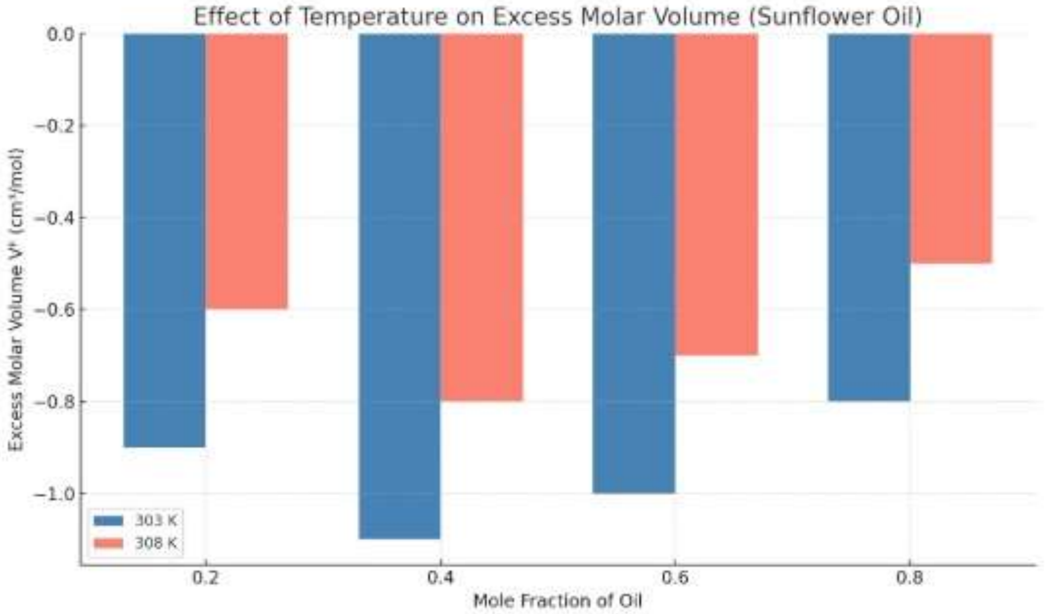


Figure 5: Here is the comparative bar chart showing the effect of temperature on excess molar volume (V^E) for sunflower oil at different mole fractions. It clearly illustrates how higher temperature (308 K) reduces the magnitude of excess volume, indicating weaker molecular interactions at elevated thermal conditions.

5. Conclusion

This study demonstrates that both sunflower and olive oils engage in notable molecular interactions with acetone–DMSO binary solvent systems, as evidenced by variations in excess acoustic and thermodynamic properties. Among the two solvents, **DMSO exhibited stronger interaction capabilities**, likely due to its higher polarity and hydrogen-bonding capacity. **Sunflower oil consistently showed more pronounced interaction effects than olive oil**, which can be attributed to differences in their fatty acid composition and polarity.

An increase in temperature from 303 K to 308 K generally led to a reduction in interaction strength, indicating the **temperature sensitivity of solute–solvent associations**. These insights are particularly relevant for the **design and optimization of oil-based formulations**, especially in pharmaceutical, cosmetic, and food-processing industries where solvent selection and thermal stability are critical.

6. Future Work

1. **Extension to Other Temperatures and Pressures**: Investigating a broader temperature and pressure range would provide deeper insights into the thermodynamic stability and molecular interactions under various industrial conditions.
2. **Molecular Dynamics Simulations**: Computational modeling can complement experimental results by visualizing molecular-level interactions and solvation behavior in acetone–DMSO systems.

3. **Effect of Solvent Composition Ratio**: Systematic variation of the acetone-to-DMSO ratio may reveal critical compositions where interaction trends shift, enabling fine-tuning of solvent systems.
4. **Study of Other Oils and Biolipids**: Including other edible and non-edible oils with varying fatty acid profiles (e.g., coconut, linseed, or castor oil) could help generalize findings and discover novel solvent–oil compatibilities.
5. **Investigation of Micellar or Emulsion Systems**: Exploring these systems could open pathways to applications in drug delivery, extraction processes, and emulsion-based formulations.
6. **Impact on Physicochemical Properties in Formulations**: Further research into how these interactions affect solubility, stability, and reactivity of oil–solvent mixtures in real-world formulations will enhance practical applications.

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