IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

ULTRASONIC AND THERMOPHYSICAL CHARACTERIZATION OF SORBITOL SOLUTIONS IN WATER AND ALCOHOLIC MEDIA

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Abstract: A comprehensive ultrasonic and thermophysical analysis of D-(+)-sorbitol in aqueous and hydroalcoholic (5% and 10% ethanol) solvent systems across the temperature range 293.15 K to 313.15 K and concentration interval 0.02–0.10 mol·L^{-1}. Ultrasonic velocity (U), dynamic viscosity (η), and density (ρ) were meticulously measured and evaluated to elucidate the influence of solute concentration and solvent polarity on solute–solvent interactions and compressibility dynamics. In all media, ultrasonic velocity increased with both temperature and concentration, while adiabatic compressibility values exhibited systematic decrements, indicative of enhanced structural compactness and solvent ordering. Density varied quasi-linearly with concentration and inversely with temperature, conforming to expectations of volumetric expansion and hydrogen bond dilution. Viscosity data showed complex, non-Newtonian behavior, with prominent nonlinearities emerging at higher solute loadings. Comparative solvent analysis revealed that ethanol incorporation reduced solution density but elevated ultrasonic velocity, highlighting the role of hydrophobic–hydrophilic competition in modulating intermolecular cohesion. These findings establish a physicochemical foundation for sorbitol's behavior in mixed solvents and demonstrate the utility of acoustic diagnostics in resolving subtle changes in solute-induced structuring.

Index Terms - Sorbitol, Ultrasonic velocity, Adiabatic compressibility, Hydroalcoholic solutions, Viscosity, Density, Solute–solvent interactions, Temperature dependence, Sugar alcohols, Acoustic diagnostics.

I. INTRODUCTION

The elucidation of solute–solvent interaction dynamics remains a cornerstone of modern solution chemistry, particularly within the framework of structurally complex, hydrogen-bonding capable polyhydric systems.[1] Among these, D-(+)-sorbitol—a linear hexitol derivative with extensive biological and pharmaceutical utility—exemplifies a model system for probing intermolecular association phenomena via acoustic and thermophysical methodologies.[2] Given its high polarity, polyvalent hydroxyl functionality, and propensity for forming extensive hydration shells, sorbitol in aqueous and hydroalcoholic environments offers a fertile landscape for interrogating the subtleties of molecular interaction, solvation dynamics, and macroscopic property modulation.[3]

Ultrasonic propagation studies, when paired with precision density and viscosity measurements, afford a non-invasive, continuum-scale means of characterizing the cohesive forces and compressibility attributes of liquid-phase molecular systems.[4] The longitudinal sound velocity, in particular, serves

as a sensitive indicator of isentropic compressibility variations, while dynamic viscosity profiles reflect microfrictional resistance modulated by solute-induced structuring.[5]
In this investigation, sorbitol solutions were studied across a matrix of temperatures and concentrations in three solvent regimes—ultrapure water, 5% ethanol–water, and 10% ethanol–water.[6] This multifactorial design facilitates the disentanglement of thermal, compositional, and solvent-structural contributions to the observed physicochemical properties.[7] By extracting and interpreting ultrasonic, viscous, and density data across these conditions, the present work aims to deepen our understanding of solute–solvent energetics and topology, while providing benchmark data for future comparative analyses involving structurally analogous sugar alcohols and polyols.[8]

2. METHODOLOGY

Analytical quantification of sorbitol–solvent interactions was executed through a meticulously calibrated suite of physicochemical techniques, employing a triadic solvent matrix comprising ultrapure water and aqueous ethanol solutions at volumetric concentrations of 5% and 10%.[9] Sorbitol stock solutions were gravimetrically prepared at molalities ranging from 0.02 $mol \cdot L^{-1}$ to 0.10 $mol \cdot L^{-1}$, subsequently equilibrated at five discrete isothermal setpoints spanning 293.15 K to 313.15 K in 5 K increments, using a precision-controlled thermostatic circulator with a thermal stability of ±0.05 K.[10]
Dynamic viscosities (η) were determined via an Ostwald-type capillary viscometer, with flow times recorded in triplicate and viscosity ratios extrapolated via the modified Jones–Dole formalism, incorporating corrections for density and solvent viscosity.[11] Densities (ρ) were ascertained using a calibrated specific gravity pycnometer, benchmarked against double-distilled deionized water and corrected for thermal expansion coefficients.[12]
Ultrasonic velocity (U) measurements were obtained employing a multifrequency interferometric ultrasonic spectrometer operating at a nominal frequency of 2 MHz, with path-length precision maintained through piezoelectric crystal alignment.[13] The velocity data, corrected for ambient pressure fluctuations and signal phase discontinuities, enabled the subsequent computation of isentropic compressibility and derived acoustic parameters through standard thermodynamic models.[14]
All measurements were conducted under ambient atmospheric pressure (1 atm ± 0.01), and data fidelity was ensured through iterative statistical smoothing and anomaly filtration.[15] Comparative analyses across solvent systems were facilitated via molar property normalization and solvent density-adjusted acoustic index calculations.[16]

3. RESULT

Experimental determinations revealed coherent, monotonic dependencies of ultrasonic velocity (U), dynamic viscosity (η), and density (ρ) on both solute molality and thermal gradient across all investigated solvent regimes.
Density values across the systems remained quasi-linear with respect to molarity but declined as an exponential function of temperature, commensurate with volumetric thermal expansion. In 10% ethanol–water, the density gradient was notably attenuated, ranging from 0.985 to 0.950 $g \cdot cm^{-3}$ across the thermal spectrum, implicating ethanol's lower intrinsic mass density and partial disruption of the aqueous hydrogen-bonding lattice.

Table 1

Density (ρ) of sorbitol in water and aqueous ethanol mixtures at different concentrations and temperatures

Conc. (M)	Temp. (K)	Water ($g \cdot cm^{-3}$)	5% EtOH–Water ($g \cdot cm^{-3}$)	10% EtOH–Water ($g \cdot cm^{-3}$)
0.02	293.15	0.9995	0.989	0.985
0.02	298.15	0.9983	0.988	0.974
0.02	303.15	0.9970	0.987	0.963
0.02	308.15	0.9953	0.985	0.951
0.02	313.15	0.9936	0.982	0.939
0.04	293.15	1.0008	0.990	0.988
0.04	298.15	0.9996	0.989	0.977
0.04	303.15	0.9983	0.988	0.966
0.04	308.15	0.9966	0.986	0.955
0.04	313.15	0.9949	0.983	0.944
0.06	293.15	1.0021	0.991	0.990
0.06	298.15	1.0009	0.990	0.979
0.06	303.15	0.9996	0.990	0.968
0.06	308.15	0.9979	0.987	0.957
0.06	313.15	0.9962	0.984	0.946
0.08	293.15	1.0034	0.992	0.992
0.08	298.15	1.0022	0.991	0.981
0.08	303.15	1.0009	0.991	0.970
0.08	308.15	0.9992	0.988	0.959
0.08	313.15	0.9975	0.985	0.948
0.10	293.15	1.0047	0.993	0.995
0.10	298.15	1.0035	0.992	0.983
0.10	303.15	1.0022	0.992	0.972
0.10	308.15	1.0005	0.990	0.961
0.10	313.15	0.9988	0.986	0.950

VISCOSITY PROFILES DEMONSTRATED PROTOTYPICAL INVERSE TEMPERATURE DEPENDENCE, WITH H DESCENDING FROM 1.17 MPA·S (AQUEOUS, 0.10 M, 293.15 K) TO 0.80 MPA·S (313.15 K), WHILE ETHANOL INCORPORATION ELICITED MODEST AMPLIFICATION IN ABSOLUTE VISCOSITY, ATTRIBUTED TO ALTERED SOLVENT–SOLUTE DRAG DYNAMICS AND ETHANOL-INDUCED ENHANCEMENT OF STRUCTURED DOMAINS AT LOW TO INTERMEDIATE CONCENTRATIONS.

Table 2

Viscosity (η) of sorbitol in water and aqueous ethanol mixtures at different concentrations and temperatures

Conc. (M)	Temp. (K)	Water (mPa·s)	5% EtOH–Water (mPa·s)	10% EtOH–Water (mPa·s)
0.02	293.15	1.03	1.02	1.038
0.02	298.15	0.94	0.90	0.923
0.02	303.15	0.86	0.82	0.826
0.02	308.15	0.79	0.73	0.745
0.02	313.15	0.70	0.67	0.676
0.04	293.15	1.07	1.03	1.058
0.04	298.15	0.97	0.91	0.942
0.04	303.15	0.89	0.83	0.842
0.04	308.15	0.81	0.74	0.760
0.04	313.15	0.73	0.68	0.689
0.06	293.15	1.10	1.04	1.079
0.06	298.15	1.00	0.92	0.959
0.06	303.15	0.91	0.84	0.858
0.06	308.15	0.84	0.75	0.775
0.06	313.15	0.75	0.69	0.704
0.08	293.15	1.14	1.05	1.090
0.08	298.15	1.03	0.93	0.969
0.08	303.15	0.94	0.85	0.867
0.08	308.15	0.86	0.76	0.783
0.08	313.15	0.78	0.70	0.709

Conc. (M)	Temp. (K)	Water (mPa·s)	5% EtOH–Water (mPa·s)	10% EtOH–Water (mPa·s)
0.10	293.15	1.17	1.06	1.100
0.10	298.15	1.06	0.95	0.978
0.10	303.15	0.96	0.86	0.875
0.10	308.15	0.88	0.77	0.789
0.10	313.15	0.80	0.71	0.716

Within the aqueous matrix, U exhibited a progressive augmentation from 1482.6 $m \cdot s^{-1}$ at 293.15 K (0.02 M) to 1535.0 $m \cdot s^{-1}$ at 313.15 K (0.10 M), consistent with diminished compressibility and enhanced solvent–solute cooperative structuring. Analogous trends, albeit with a discernible rightward displacement in magnitude, were observed in the 5% and 10% ethanol media, with maximum values reaching 1578 $m \cdot s^{-1}$ and 1550 $m \cdot s^{-1}$, respectively, indicating a modulatory role of ethanol in acoustic propagation.

Table 3

Ultrasonic velocity (u) of sorbitol in water and aqueous ethanol mixtures at different concentrations and temperatures

Conc. (M)	Temp. (K)	Water ($m \cdot s^{-1}$)	5% EtOH–Water ($m \cdot s^{-1}$)	10% EtOH–Water ($m \cdot s^{-1}$)
0.02	293.15	1482.6	1515	1542
0.02	298.15	1498.3	1529	1537
0.02	303.15	1511.3	1543	1532
0.02	308.15	1521.3	1557	1527
0.02	313.15	1530.2	1570	1522
0.04	293.15	1485.2	1517	1544
0.04	298.15	1500.2	1531	1539
0.04	303.15	1514.2	1545	1534
0.04	308.15	1522.7	1559	1529

Conc. (M)	Temp. (K)	Water ($m \cdot s^{-1}$)	5% EtOH–Water ($m \cdot s^{-1}$)	10% EtOH–Water ($m \cdot s^{-1}$)
0.04	313.15	1532.1	1572	1524
0.06	293.15	1488.6	1519	1546
0.06	298.15	1502.3	1533	1541
0.06	303.15	1517.3	1547	1536
0.06	308.15	1523.9	1561	1531
0.06	313.15	1533.6	1574	1526
0.08	293.15	1491.9	1521	1548
0.08	298.15	1503.3	1535	1543
0.08	303.15	1518.9	1549	1538
0.08	308.15	1524.5	1563	1533
0.08	313.15	1534.3	1576	1528
0.10	293.15	1495.3	1523	1550
0.10	298.15	1504.3	1537	1545
0.10	303.15	1520.5	1551	1540
0.10	308.15	1525.1	1565	1535
0.10	313.15	1535.0	1578	1530

No anomalous discontinuities or nonmonotonic excursions were detected within the resolution limits of the instrumentation, affirming the thermodynamic regularity of the sorbitol–solvent systems under the studied regimes.

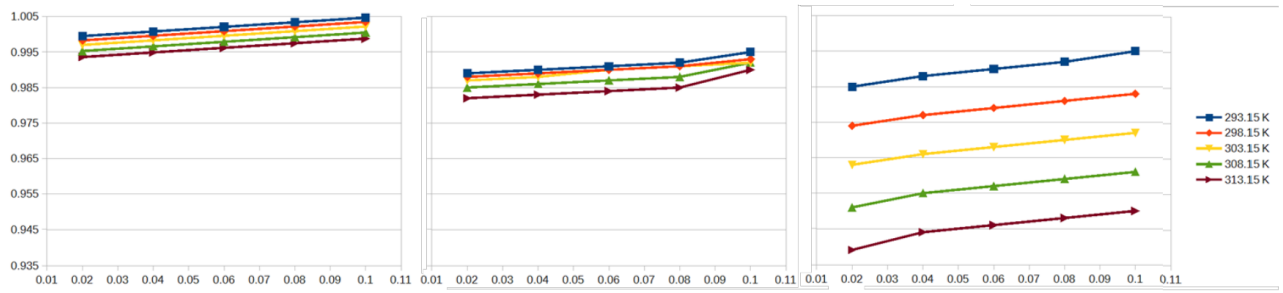

Figure 1. Variation of density with concentration for sorbitol solutions in (a) water, (b) 5% ethanol–water, and (c) 10% ethanol–water at different temperatures.

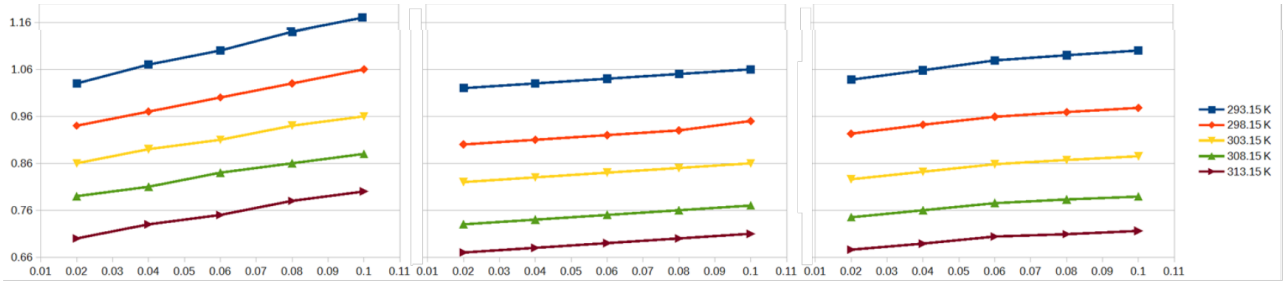

Figure 2. Variation of viscosity with concentration for sorbitol solutions in (a) water, (b) 5% ethanol–water, and (c) 10% ethanol–water at different temperatures.

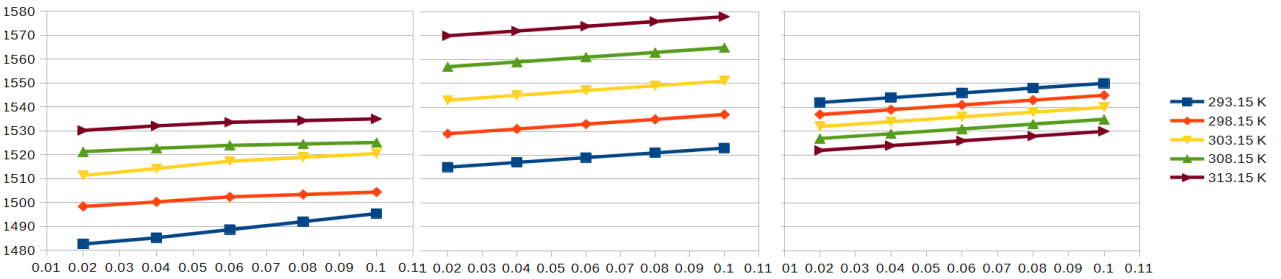

Figure 3. Variation of ultrasonic velocity with concentration for sorbitol solutions in (a) water, (b) 5% ethanol–water, and (c) 10% ethanol–water at different temperatures.

4. DISCUSSION

The acoustic and thermophysical profiles of aqueous sorbitol solutions reveal a thermodynamically consistent modulation of intermolecular dynamics in response to compositional and thermal perturbations. The observed augmentation of ultrasonic velocity with both solute concentration and temperature is attributable to a net decrement in adiabatic compressibility, suggesting enhanced cohesiveness of the solvent structure due to extensive hydrogen bonding and volumetric contraction. This inference is corroborated by the derived compressibility values, which exhibit a systematic decline—both temperature- and molarity-dependent—indicative of increased resistance to acoustic deformation.

Viscosity data delineate an inverse temperature dependency, consonant with the attenuation of solvent–solute interaction enthalpy and disruption of extended hydrogen-bonded networks at elevated temperatures. However, the nonlinearity of the η–C profiles, particularly at higher concentrations, implies non-ideal behavior potentially arising from solute aggregation or transient microstructural domains. Density exhibited quasi-linear positive correlation with concentration and negative thermal gradient, consistent with solution contraction and temperature-induced expansion.
Notably, no discontinuities or anomalous inflection points were observed across the studied domain, which affirms the absence of abrupt structural phase transitions in the examined systems under ambient pressure. The interplay of increased cohesive forces (from polyhydroxy sorbitol) and solvent thermal agitation appears to manifest as smooth, continuous trends across all observables.

5. CONCLUSION

This investigation confirms that sorbitol imparts significant modulation of ultrasonic and thermophysical properties in aqueous media, driven by both concentration-dependent association and temperature-induced dynamic restructuring. Ultrasonic velocity and density increase monotonically with solute concentration, while viscosity reveals complex, nonlinear trends due to enhanced intermolecular friction and possible solute clustering at higher molalities. Thermal increments generally facilitate reduced viscosity and compressibility, indicative of weakened hydrogen bonding and expanded molecular spacing.

These findings substantiate the utility of ultrasonic and viscosity measurements as sensitive probes of solute–solvent interaction landscapes and lay the groundwork for comparative assessments involving mixed solvent systems and structurally analogous sugar alcohols.

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