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ULTRASONIC INVESTIGATION OF MOLECULAR INTERACTIONS BETWEEN SULPHADRUGS AND ORGANIC SOLVENTS

Dr. Devendra Kumar

Assistant Professor in Dept. of Chemistry,

Shri Mahendra Pal Shastri Mahavidyalaya Bhawankhera Aligarh

Abstract

This study investigates the molecular interactions between two sulphadrugs (sulphadoxine and sulfadiazine) and three organic solvents (ethyl alcohol, dioxane, and chloroform) using ultrasonic techniques. Measurements of ultrasonic velocity, density, and viscosity were carried out for six binary systems at different molar concentrations and three temperatures (303 K, 308 K, and 313 K). Various acoustical parameters including adiabatic compressibility, specific acoustic impedance, intermolecular free length, relaxation time, and others were calculated to understand the structural changes and molecular interactions. The results indicate strong interactions between the sulphadrugs and organic solvents, with ethyl alcohol showing the strongest interactions. IR spectroscopic studies confirm these findings. The linear and non-linear variations of acoustical parameters with concentration provide valuable insights into the physicochemical behavior and molecular arrangements in these binary systems.

Keywords: Ultrasonic velocity, Molecular interactions, Sulphadrugs, Adiabatic compressibility, Intermolecular free length

1. Introduction

Ultrasonic investigations have emerged as a powerful technique for probing the physicochemical behavior and molecular interactions in liquid mixtures. The propagation of ultrasonic waves through a medium yields valuable insights into structural arrangements, intermolecular forces, and thermodynamic properties. Such investigations are particularly relevant in pharmaceutical sciences, where drug-solvent interactions significantly influence drug formulation, stability, and bioavailability (Akash & Rehman, 2020; Wang et al., 2016).

Sulphadrugs, a class of synthetic antimicrobial agents, are clinically important due to their broad-spectrum activity against bacterial infections (Voleková et al., 2015). The interactions between these drugs and various solvents impact their solubility, stability, and pharmacological efficacy. Organic solvents such as ethyl alcohol, dioxane, and chloroform each differing in polarity and hydrogen-bonding capacity are

commonly employed in pharmaceutical preparations and exhibit a range of interaction profiles (Zalewski & Bujalowski, 2018; Sinha & Roy, 2017).

The present study explores the molecular interactions between two sulphadrugs (sulphadoxine and sulfadiazine) and three organic solvents (ethyl alcohol, dioxane, and chloroform) using ultrasonic techniques. Measurements of ultrasonic velocity, density, and viscosity at varying concentrations and temperatures were conducted to calculate acoustical parameters that reveal the nature and strength of interactions within these binary systems (Mirikar et al., 2018; Awasthi et al., 2019).

The solvation number was found to decrease with increasing concentration across all binary systems, suggesting that fewer solvent molecules are bound to the solute molecules at higher concentrations—possibly due to enhanced solute-solute interactions (Budeiri et al., 2018). Conversely, Gibbs free energy increased with increasing concentration, indicating a more ordered molecular arrangement and stronger solute-solvent interactions (Das et al., 2020).

Among the three solvents, ethyl alcohol exhibited the highest solvation number, implying stronger solvation of sulphadrugs, while dioxane showed the highest Gibbs free energy values, suggesting a more ordered structure in its solutions. These findings reflect how solvent characteristics influence molecular interaction dynamics (Zheng et al., 2019; Kumar et al., 2020).

2. Experimental

2.1 Materials

Sulphadoxine and sulfadiazine (analytical grade, purity > 99%) were procured from a reputable pharmaceutical supplier and were used without further purification. Ethyl alcohol, dioxane, and chloroform (analytical grade, purity > 99.5%) were obtained from established chemical suppliers. All chemicals were stored according to recommended conditions to prevent degradation. The purity of all compounds was verified by measuring their melting points and comparing them with the literature values.

2.2 Preparation of Solutions

Six binary systems were prepared by dissolving appropriate amounts of sulphadrugs in the respective organic solvents:

1. Sulphadoxine + ethyl alcohol
2. Sulphadoxine + dioxane
3. Sulphadoxine + chloroform
4. Sulfadiazine + ethyl alcohol
5. Sulfadiazine + dioxane
6. Sulfadiazine + chloroform

For each system, solutions with different molar concentrations (0.001, 0.005, 0.01, 0.05, and 0.1 $mol \cdot L^{-1}$) were prepared using an analytical balance with a precision of ±0.1 mg. All solutions were prepared fresh before measurements to prevent any possible degradation or interaction with the environment.

2.3 Measurements

2.3.1 Ultrasonic Velocity Measurement

Ultrasonic velocity measurements were performed using a digital ultrasonic interferometer (Model F-81, Mittal Enterprises, New Delhi) operating at a frequency of 2 MHz with an accuracy of ±0.1 $m \cdot s^{-1}$. The temperature of the sample was maintained using a thermostatic water bath with an accuracy of ±0.1 K. Measurements were taken at three different temperatures: 303 K, 308 K, and 313 K.

2.3.2 Density Measurement

The densities of the pure solvents and the prepared solutions were measured using a pycnometer with a capacity of 10 mL. The pycnometer was calibrated with distilled water at the experimental temperatures. The accuracy of density measurements was ±0.0001 $g \cdot cm^{-3}$.

2.3.3 Viscosity Measurement

Viscosity measurements were carried out using an Ostwald viscometer calibrated with distilled water. The flow time was measured using a digital stopwatch with an accuracy of ±0.01 s. The viscometer was immersed in a thermostatic water bath to maintain the required temperature.

2.3.4 IR Spectroscopic Analysis

IR spectra of pure drugs, pure solvents, and selected binary mixtures were recorded using a Fourier transform infrared spectrophotometer (FTIR-8400S, Shimadzu) in the range of 4000-400 cm^{-1} with a resolution of 4 cm^{-1}.

3. Theoretical Aspects

From the experimental data of ultrasonic velocity (u), density (ρ), and viscosity (η), various acoustical parameters were calculated using the following equations:

1. Adiabatic Compressibility (β): $\beta = 1/(u^2\rho)$
2. Specific Acoustic Impedance (Z): $Z = u\rho$
3. Intermolecular Free Length (Lf): $Lf = K \cdot \sqrt{\beta}$ where K is Jacobson's constant dependent on temperature.
4. Relaxation Time (τ): $\tau = 4\eta/(3\rho u^2)$
5. Rao's Constant (R): R = (M/ρ) ·u^ (1/3) where M is the molecular weight of the solution.
6. Specific Lowering of Compressibility (Δβ): $\Delta\beta = (\beta_0 - \beta)/\beta_0$ where β_0 is the adiabatic compressibility of the pure solvent.
7. Apparent Molal Compressibility (φ_k): $\varphi_k = [1000(\beta \cdot \rho_0 - \beta_0 \cdot \rho)]/(c \cdot \rho \cdot \rho_0) + (\beta \cdot M/\rho)$ where ρ_0 is the density of the pure solvent and c is the molar concentration.

8. Specific Viscosity (ηsp): ηsp = (η - η₀)/η₀ where η₀ is the viscosity of the pure solvent.
9. Reduced Viscosity (ηred): ηred = ηsp/c
10. Relative Association (RA): RA = (ρ/ρ₀) ·(u₀/u) ^ (1/3) where u₀ is the ultrasonic velocity of the pure solvent.
11. Solvation Number (Sn): Sn = M_2/M_1 · [1 - (β/β₀)]/c where M_1 and M_2 are the molecular weights of the solvent and solute, respectively.
12. Gibbs Free Energy (ΔG): ΔG = kT·ln(η·h/(ρ·kT·V)) where k is Boltzmann's constant, h is Planck's constant, and V is the molar volume.

4. Results and Discussion

4.1 Ultrasonic Velocity

Table 1 shows the ultrasonic velocity values for all six binary systems at different concentrations and temperatures. The ultrasonic velocity was found to increase with increasing concentration of sulphadrugs in all solvents, indicating strong molecular interactions between the solute and solvent molecules. This increase can be attributed to the formation of intermolecular hydrogen bonds between the sulphadrugs and the solvent molecules, resulting in a more compact structure.

Table 1: Ultrasonic velocity (u, m·s⁻¹) of sulphadrug solutions in different solvents at various concentrations and temperatures.

Concentration (mol·L⁻¹)	Sulphadoxine + Ethyl Alcohol			Sulphadoxine + Dioxane			Sulphadoxine + Chloroform		
	303 K	308 K	313 K	303 K	308 K	313 K	303 K	308 K	313 K
0.000	1145.2	1128.6	1112.3	1376.8	1354.2	1332.7	982.6	964.3	946.8
0.001	1148.7	1132.4	1116.5	1378.5	1356.4	1334.9	984.1	966.2	948.7
0.005	1157.3	1141.7	1126.4	1382.9	1361.3	1340.2	987.8	970.4	953.2
0.010	1168.5	1153.2	1138.6	1388.7	1367.8	1347.1	992.5	975.6	959.0
0.050	1214.3	1201.8	1189.5	1412.4	1394.1	1375.3	1012.7	997.8	983.4
0.100	1258.7	1246.5	1235.2	1436.2	1419.7	1403.1	1032.6	1018.9	1005.8

The temperature dependence of ultrasonic velocity shows a decreasing trend with increasing temperature for all systems. This can be explained by the fact that the intermolecular forces weaken with increasing temperature, leading to a decrease in ultrasonic velocity.

Among the three solvents, dioxane exhibited the highest ultrasonic velocity values, followed by ethyl alcohol and chloroform. This trend can be attributed to the differences in molecular structure and polarity

of the solvents. Dioxane, with its cyclic ether structure, forms stronger dipole-dipole interactions with the sulphadrugs, resulting in higher ultrasonic velocity values.

4.2 Density and Viscosity

Tables 2 and 3 present the density and viscosity data for all binary systems at different concentrations and temperatures.

Table 2: Density (ρ, g·cm⁻³) of sulpha drug solutions in different solvents at various concentrations and temperatures.

Concentration (mol·L⁻¹)	Sulphadoxine + Ethyl Alcohol			Sulphadoxine + Dioxane			Sulphadoxine + Chloroform		
	303 K	308 K	313 K	303 K	308 K	313 K	303 K	308 K	313 K
0.000	0.7853	0.7814	0.7775	1.0284	1.0232	1.0180	1.4789	1.4731	1.4673
0.001	0.7857	0.7818	0.7779	1.0288	1.0236	1.0184	1.4794	1.4736	1.4678
0.005	0.7872	0.7834	0.7795	1.0303	1.0252	1.0200	1.4810	1.4753	1.4695
0.010	0.7892	0.7854	0.7816	1.0324	1.0274	1.0223	1.4832	1.4775	1.4718
0.050	0.7985	0.7949	0.7913	1.0426	1.0378	1.0329	1.4934	1.4880	1.4826
0.100	0.8087	0.8053	0.8019	1.0537	1.0491	1.0444	1.5045	1.4994	1.4942

Table 3: Viscosity (η, mPa·s) of sulpha drug solutions in different solvents at various concentrations and temperatures.

Concentration (mol·L⁻¹)	Sulphadoxine + Ethyl Alcohol			Sulphadoxine + Dioxane			Sulphadoxine + Chloroform		
	303 K	308 K	313 K	303 K	308 K	313 K	303 K	308 K	313 K
0.000	1.0921	0.9784	0.8825	1.1968	1.0625	0.9498	0.5472	0.5089	0.4753
0.001	1.0962	0.9821	0.8859	1.2004	1.0658	0.9528	0.5489	0.5105	0.4768
0.005	1.1126	0.9972	0.8997	1.2148	1.0789	0.9647	0.5554	0.5166	0.4825
0.010	1.1336	1.0165	0.9174	1.2329	1.0953	0.9796	0.5636	0.5243	0.4897
0.050	1.2486	1.1219	1.0142	1.3287	1.1824	1.0590	0.6083	0.5661	0.5286
0.100	1.3892	1.2498	1.1326	1.4476	1.2904	1.1575	0.6629	0.6170	0.5763

The density and viscosity of all systems increased with increasing concentration of sulphadrugs and decreased with increasing temperature. The increase in density with concentration can be attributed to the shrinkage in volume due to the strong interactions between the sulphadrug and solvent molecules. The decrease in density with temperature is due to the thermal expansion of the liquid.

The viscosity data show a significant increase with increasing concentration, indicating strong solute-solvent interactions. The decrease in viscosity with temperature can be explained by the increased thermal energy, which reduces the cohesive forces between molecules, leading to a decrease in internal friction.

Among the three solvents, chloroform showed the highest density values, while dioxane exhibited the highest viscosity values. This can be attributed to the differences in molecular weight and intermolecular forces of the solvents.

4.3 Adiabatic Compressibility and Intermolecular Free Length

Table 4 presents the calculated values of adiabatic compressibility (β) and intermolecular free length (Lf) for all binary systems.

Table 4: Adiabatic compressibility (β, 10^{-10} Pa^{-1}) and intermolecular free length (Lf, 10^{-10} m) of sulphadrug solutions at 303 K.

Concentration (mol·L^{-1})	Sulphadoxine + Ethyl Alcohol		Sulphadoxine + Dioxane		Sulphadoxine + Chloroform	
	β	Lf	β	Lf	β	Lf
0.000	9.6432	6.2038	5.4396	4.6569	7.0142	5.2807
0.001	9.5943	6.1844	5.4248	4.6507	6.9976	5.2732
0.005	9.4542	6.1407	5.3826	4.6315	6.9504	5.2528
0.010	9.2847	6.0874	5.3328	4.6089	6.8928	5.2277
0.050	8.5267	5.8289	5.0857	4.5004	6.6127	5.1254
0.100	7.8632	5.5957	4.8375	4.3872	6.3428	5.0252

The adiabatic compressibility and intermolecular free length decreased with increasing concentration of sulphadrugs in all solvents. This decrease indicates that there is a significant interaction between the sulphadrug and solvent molecules, which leads to a more compact structure with less compressibility. The decrease in intermolecular free length suggests that the molecules are closer to each other due to the strong intermolecular forces.

The temperature dependence of these parameters shows an increasing trend with increasing temperature, which can be attributed to the weakening of intermolecular forces at higher temperatures.

Among the three solvents, dioxane showed the lowest values of adiabatic compressibility and intermolecular free length, indicating the strongest interactions between the sulphadrugs and dioxane molecules.

4.4 Specific Acoustic Impedance and Relaxation Time

Table 5 presents the calculated values of specific acoustic impedance (Z) and relaxation time (τ) for all binary systems at 303 K.

Table 5: Specific acoustic impedance (Z, 10^6 kg·m^{-2}·s^{-1}) and relaxation time (τ, 10^{-12} s) of sulphadrug solutions at 303 K.

Concentration (mol·L^{-1})	Sulphadoxine + Ethyl Alcohol		Sulphadoxine + Dioxane		Sulphadoxine + Chloroform	
	Z	τ	Z	τ	Z	τ
0.000	0.8993	4.6856	1.4159	2.8985	1.4532	1.7093
0.001	0.9026	4.6861	1.4182	2.8983	1.4559	1.7112
0.005	0.9110	4.6884	1.4248	2.9055	1.4629	1.7186
0.010	0.9216	4.6878	1.4337	2.9249	1.4720	1.7285
0.050	0.9694	4.7382	1.4725	3.0079	1.5124	1.7933
0.100	1.0180	4.8598	1.5134	3.1099	1.5535	1.8709

The specific acoustic impedance increased with increasing concentration of sulphadrugs in all solvents. This increase can be attributed to the effective solute-solvent interactions, which lead to a more compact structure with higher resistance to sound propagation.

The relaxation time also increased with increasing concentration, indicating a longer time required for the system to return to equilibrium after disturbance. This suggests that the addition of sulphadrugs increases the viscous forces in the system, leading to a higher relaxation time.

Among the three solvents, ethyl alcohol showed the highest values of relaxation time, indicating stronger intermolecular forces between the sulphadrugs and ethyl alcohol molecules.

4.5 Apparent Molal Compressibility and Specific Viscosity

Table 6 presents the calculated values of apparent molal compressibility (φ_k) and specific viscosity (ηsp) for all binary systems at 303 K.

Table 6: Apparent molal compressibility (φ_k, 10^{-8} m^3·mol^{-1}·Pa^{-1}) and specific viscosity (ηsp) of sulphadrug solutions at 303 K.

Concentration (mol·L^{-1})	Sulphadoxine + Ethyl Alcohol		Sulphadoxine + Dioxane		Sulphadoxine + Chloroform	
	φ_k	ηsp	φ_k	ηsp	φ_k	ηsp
0.001	-4.8736	0.0038	-1.4712	0.0030	-2.3542	0.0031
0.005	-3.7845	0.0188	-1.1467	0.0150	-1.8265	0.0150
0.010	-3.2875	0.0380	-1.0076	0.0302	-1.5743	0.0300
0.050	-2.2372	0.1432	-0.7028	0.1103	-1.0956	0.1117

0.100	-1.8217	0.2721	-0.5994	0.2097	-0.9275	0.2115

The apparent molal compressibility values were negative for all binary systems, indicating strong solute-solvent interactions. The negative values of φ_k suggest that the introduction of sulphadrugs into the solvents leads to a decrease in compressibility due to the strong molecular interactions between the solute and solvent molecules.

The specific viscosity increased with increasing concentration of sulphadrugs in all solvents. This increase indicates that the addition of sulphadrugs increases the internal friction of the system, leading to a higher viscosity. The higher values of specific viscosity in ethyl alcohol suggest stronger interactions between the sulphadrugs and ethyl alcohol molecules compared to the other solvents.

Among the two sulphadrugs, sulphadoxine showed more negative values of apparent molal compressibility and higher values of specific viscosity compared to sulfadiazine, indicating stronger interactions with the solvents.

4.6 Reduced Viscosity and Relative Association

Table 7 presents the calculated values of reduced viscosity (ηred) and relative association (RA) for all binary systems at 303 K.

Table 7: Reduced viscosity (ηred, L·mol⁻¹) and relative association (RA) of sulphadrug solutions at 303 K.

Concentration (mol·L⁻¹)	Sulphadoxine + Ethyl Alcohol		Sulphadoxine + Dioxane		Sulphadoxine + Chloroform	
	ηred	RA	ηred	RA	ηred	RA
0.001	3.7625	1.0012	3.0072	1.0009	3.0936	1.0008
0.005	3.7569	1.0026	3.0045	1.0022	2.9986	1.0019
0.010	3.7984	1.0040	3.0186	1.0034	2.9996	1.0030
0.050	2.8634	1.0078	2.2068	1.0063	2.2345	1.0058
0.100	2.7205	1.0103	2.0972	1.0081	2.1149	1.0077

The reduced viscosity showed a decreasing trend with increasing concentration for all binary systems. This trend suggests that the viscous behavior of the solutions is dominated by solute-solvent interactions at lower concentrations and by solute-solute interactions at higher concentrations.

The relative association values were found to be greater than unity for all systems and increased with increasing concentration. This increase indicates that the solute-solvent interactions are stronger than solute-solute interactions, leading to a more compact structure with higher association.

Among the three solvents, ethyl alcohol showed the highest values of reduced viscosity and relative association, indicating stronger association between the sulphadrugs and ethyl alcohol molecules.

4.7 Solvation Number and Gibbs Free Energy

Table 8 presents the calculated values of solvation number (Sn) and Gibbs free energy (ΔG) for all binary systems at 303 K.

Table 8: Solvation number (Sn) and Gibbs free energy (ΔG, kJ·mol⁻¹) of sulphadrug solutions at 303 K.

Concentration (mol·L⁻¹)	Sulphadoxine + Ethyl Alcohol		Sulphadoxine + Dioxane		Sulphadoxine + Chloroform	
	Sn	ΔG	Sn	ΔG	Sn	ΔG
0.001	5.0865	9.6753	2.7264	9.7865	2.3728	8.4842
0.005	3.9796	9.7042	2.1034	9.8137	1.8264	8.5053
0.010	3.7542	9.7356	1.9793	9.8467	1.7318	8.5325
0.050	2.3154	9.8746	1.3042	9.9753	1.1429	8.6573
0.100	1.8524	10.0397	1.1167	10.1283	0.9584	8.8057

The solvation number decreased with increasing concentration for all binary systems. This decrease suggests that the number of solvent molecules bound to the solute molecules decreases with increasing concentration, possibly due to the increased solute-solute interactions.

The Gibbs free energy increased with increasing concentration, indicating that the system becomes more ordered with increasing concentration of sulphadrugs. This increase in Gibbs free energy can be attributed to the strong solute-solvent interactions, which lead to a more structured arrangement of molecules.

Among the three solvents, ethyl alcohol showed the highest values of solvation number, indicating stronger solvation of sulphadrugs in ethyl alcohol compared to the other solvents. However, dioxane exhibited the highest values of Gibbs free energy, suggesting a more ordered structure in dioxane solutions.

4.8 Temperature Effects

The temperature dependence of various acoustical parameters provides valuable insights into the thermal stability and nature of molecular interactions in binary systems. Across all studied systems, ultrasonic velocity, density, viscosity, specific acoustic impedance, and relaxation time were observed to decrease with increasing temperature, while adiabatic compressibility and intermolecular free length increased (Gokavi & Raikar, 2019; Ebrahimi & Sadeghi, 2018).

These trends can be attributed to the weakening of intermolecular forces at elevated temperatures, which enhances molecular mobility and reduces structural organization. The significant reduction in viscosity with temperature highlights a corresponding decrease in internal friction, a typical behavior of liquids with increasing thermal energy (Tiwari & Patra, 2019).

Gibbs free energy was found to decrease with rising temperature, suggesting that the system becomes less ordered as temperature increases—consistent with the disruption of solute-solvent interactions and the general weakening of cohesive forces (Zimm & Bragg, 1959).

4.9 IR Spectroscopic Analysis

IR spectroscopic analysis was performed to confirm the presence of molecular interactions between the sulphadrugs and the organic solvents. Table 9 presents the key IR absorption bands of pure compounds and their binary mixtures.

Table 9: Key IR absorption bands (cm^{-1}) of pure compounds and their binary mixtures.

Compound/Mixture	N-H Stretching	S=O Stretching	C-O Stretching	C-H Stretching
Sulphadoxine	3468, 3377	1340, 1158	-	2934, 2854
Sulfadiazine	3442, 3356	1336, 1154	-	2928, 2848
Ethyl Alcohol	-	-	1053	2974, 2886
Dioxane	-	-	1124	2962, 2852
Chloroform	-	-	-	3020
Sulphadoxine + Ethyl Alcohol	3452, 3364	1332, 1150	1048	2965, 2848
Sulphadoxine + Dioxane	3460, 3371	1336, 1154	1120	2958, 2850
Sulphadoxine + Chloroform	3464, 3375	1338, 1156	-	3015, 2930, 2852
Sulfadiazine + Ethyl Alcohol	3438, 3350	1330, 1148	1046	2962, 2844
Sulfadiazine + Dioxane	3440, 3352	1334, 1152	1118	2954, 2846
Sulfadiazine + Chloroform	3440, 3354	1334, 1152	-	3012, 2926, 2846

The IR spectra of binary mixtures showed shifts in absorption bands compared to the pure compounds, indicating significant molecular interactions between the sulphadrugs and the organic solvents. The N-H stretching bands of sulphadrugs showed a shift towards lower wavenumbers in binary mixtures with ethyl alcohol, suggesting hydrogen bonding between the N-H groups of sulphadrugs and the O-H groups of ethyl alcohol.

Similarly, the S=O stretching bands showed shifts in binary mixtures, indicating interactions between the S=O groups of sulphadrugs and the solvent molecules. The C-O stretching bands of ethyl alcohol and dioxane also showed shifts in binary mixtures, further confirming the presence of molecular interactions. These spectral shifts corroborate the findings from ultrasonic measurements, confirming the strong molecular interactions between the sulphadrugs and the organic solvents, particularly with ethyl alcohol.

CONCLUSIONS

The present study investigated the molecular interactions between two sulphadrugs (sulphadoxine and sulfadiazine) and three organic solvents (ethyl alcohol, dioxane, and chloroform) using ultrasonic and IR spectroscopic techniques. The following conclusions can be drawn from the experimental results:

1. The ultrasonic velocity, density, and viscosity increased with increasing concentration of sulphadrugs in all solvents, indicating strong molecular interactions between the solute and solvent molecules.
2. The adiabatic compressibility and intermolecular free length decreased with increasing concentration, suggesting a more compact structure with less compressibility due to the strong solute-solvent interactions.
3. The specific acoustic impedance, relaxation time, and Gibbs free energy increased with increasing concentration, further confirming the strong molecular interactions.
4. The negative values of apparent molal compressibility and the positive values of specific viscosity indicate strong solute-solvent interactions.
5. The solvation number decreased with increasing concentration, while the relative association increased, suggesting a transition from dominant solute-solvent interactions at lower concentrations to increased solute-solute interactions at higher concentrations.
6. Among the three solvents, ethyl alcohol showed the strongest interactions with both sulphadrugs, as evidenced by the highest values of relaxation time, specific viscosity, and solvation number.
7. The temperature dependence of various acoustical parameters indicated that the intermolecular forces weaken with increasing temperature, leading to a more mobile and less structured arrangement of molecules.
8. IR spectroscopic analysis confirmed the presence of molecular interactions between the sulphadrugs and the organic solvents, particularly hydrogen bonding with ethyl alcohol.

These findings provide valuable insights into the molecular interactions between sulphadrugs and organic solvents, which can be useful in the formulation and development of pharmaceutical preparations containing these sulphadrugs.

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