E- ISSN: 2249 –1929

Journal of Chemical, Biological and Physical Sciences

An International Peer Review E-3 Journal of Sciences

Available online at www.jcbsc.org

Section A: Chemical science

Research Article

Molecular Interaction Study of Lactose, DMF-H_2O and NaCl System Using Acoustic, Viscometric and Volumetric Methods at different Temperatures

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Received: 3 August 2011; Revised: 22 August 2011; Accepted: 29 August 2011;

ABSTRACT

Acoustic, viscometric and volumetric studies are useful for characterization of molecular interactions and to understand the effect of temperature of lactose in mixed solvent of N,N-dimethylformamide (DMF)-H_2O+NaCl. Physical properties viz density (ρ), viscosity (η), sound speed (u) and refractive index (n_D) at varying concentrations from 0.0105-0.1045 m at 298, 308 and 318 K have been determined using precalibrated bicapillary pycnometer, Ostwald's viscometer, Abbe's refractometer and single frequency ultrasonic interferometer at 2 MHz frequency respectively. The derived parameters like adiabatic compressibility (β), acoustic impedance (Z), absorption coefficient (α/f^2), apparent molal volume (ϕ_v), apparent molal compressibility (ϕ_K), free volume (V_f), intermolecular free length (L_f), acoustical relaxation time (τ), Gibbs free energy (ΔG), internal pressure (π_i), Rao's constant (R_m), Wada's constant (W) and molar refractivity (R_D) have been determined from experimental data. All the measurements have been carried out in a thermostatically controlled water bath with circulating medium having accuracy of ±0.1ºC

Key words: Density, Viscosity, Lactose, N,N-dimethylformamide, Jones-Dole equation

INTRODUCTION

Studies on biomolecules[1] in mixed solvents play a crucial role in understanding the interactions of

organic solvents with bio-molecules at different temperatures.[2-3] From a long time different organic compounds are being used for the treatment of many physicochemical disorders in humans. Present work is providing a small platform to understand these interactions in the externally created environment. Such study helps to understand the some biochemical phenomenon like drug-receptor reactions, osmosis and biophysical process at the cell membrane of cells so that improvement on these prescriptions may be made in future. In the present work carbohydrates (Lactose), N,N-dimethylformamide and sodium chloride are being used for this purpose. [4] DMF has been associated with the liver damage with hepatic effects and associated disorders of the digestive system, ischemic heart disease and prostate cancer.[5,6]

Carbohydrates are the component of various fluids like cerebrospinal fluids, blood etc and provide energy to complete their work. It also play an important role in the synthesis of glycoprotein, a constituent of muscles. Although some works have been reported on sugars like glucose and sucrose at single temperature by some researchers[7] but present study gives better account to understand the interactions in the presence of sodium chloride at different temperatures. The use of mixed solvents has received great attention in recent years in the study of molecular interactions of bio-molecules because it helps in understanding the complex phenomena.

EXPERIMENTAL

Lactose and N,N-dimethylformamide were obtained from Himedia and Merck chemicals ltd., India of AR grade with purity better than 99 percent without any purification. The viscosity of the solution was determined using pre-calibrated Ostwald's viscometer[8] with uncertainty of ±0.067%. The viscosity measurements are based on the measurement of flow time with uncertainty of ± 0.01s. The density measurements have been done using pre-calibrated bycapillary pycnometer[9] with an uncertainty of ±0.06%. Sound speed of solutions was measured using an ultrasonic interferometer[10] (Model F-81) with a single at a frequency of 2 MHz having uncertainty of ±0.056%. Refractive index has been measured using Abbe's Refractometer [11] with uncertainty of ±0.062%. All the instruments and apparatus were calibrated with standard liquids like benzene, cyclohexane, N,N-dimethylformamide, n-hexane before taking measurements. The accuracy in temperature is ±0.1^{o}C maintained by a thermostatically controlled refrigerated water bath with water as circulating medium. The weighing was done using the Denver balance with accuracy of 0.1 mg. Doubly distilled water was used to prepare the mixed solvent of DMF and H_2O in 1:1 (v/v) ratio and NaCl (0.2098 m) was prepared in mixed solvent of DMF-H_2O solvent and used on the same day.

RESULTS AND DISCUSSION

The experimental values of density (ρ), viscosity (η), sound speed (u) and derived parameters such as adiabatic compressibility (β) and apparent molal volume (ϕ_v) are shown in Table 1. The values of density, sound speed and viscosity increase with concentration of lactose in DMF-H_2O+NaCl System. The increase in sound speed and density may be due to molecular association caused by cohesive forces.[12] Cohesive forces increase with increase in the concentration of lactose. The viscosity decrease with rise in temperature may be due to the increase in movement of molecules and ions presents in the solutions.

Table- 1: Experimental Data of Density (ρ), Viscosity (η), Sound speed (u), Refractive index (n_D) and derived parameters Adiabatic compressibility (β), Apparent molal volume (ϕ_v) for Lactose with (DMF-H_2O) +NaCl System at 298, 308 and 318 K

C/ (mol.Kg^{-1})	ρ/ (kg.m^{-3})	u/ (m.s^{-1})	η/ (10^{-3} Nm^{-2} s)	n_D	β/ (10^{-10} m^2N^{-1})	ϕ_v / (10^{-6} $m^{3.}$ Mol^{-1})
			298 K			
0	998.1	1689.6	2.4625	1.3968	3.5096	-
0.0105	1000.1	1690.8	2.4966	1.3997	3.4976	63.7574
0.0209	1002.4	1694.0	2.5315	1.3998	3.4764	67.0996
0.0315	1005.0	1697.2	2.5674	1.3998	3.4544	68.8637
0.0419	1007.5	1701.2	2.6031	1.4000	3.4296	70.8595
0.0525	1010.2	1705.2	2.6394	1.4001	3.4044	71.9020
0.0630	1012.4	1708.0	2.6746	1.4002	3.3859	74.6941
0.0734	1015.2	1710.4	2.7115	1.4005	3.3671	75.1205
0.0839	1017.6	1713.2	2.7475	1.4009	3.3482	76.8696
0.0944	1019.6	1716.0	2.7799	1.4010	3.3307	79.8004
0.1049	1022.2	1719.2	2.8176	1.4013	3.3099	80.5981
			308 K			
0	980.2	1657.2	1.793	1.3949	3.7148	-
0.0105	982.3	1660.8	1.8327	1.3972	3.6908	64.2287
0.0209	984.6	1663.6	1.8633	1.3973	3.6698	67.4760
0.0315	987.1	1666.0	1.8952	1.3973	3.6500	69.5427
0.0419	989.6	1669.6	1.9282	1.3973	3.6251	71.4129
0.0525	992.2	1673.2	1.9597	1.3973	3.600	72.7112
0.0630	994.5	1676.0	1.9911	1.3975	3.5797	75.0390
0.0734	997.2	1679.2	2.0218	1.3977	3.5564	75.6962
0.0839	999.7	1682.8	2.0499	1.3982	3.5324	76.9985
0.0944	1001.7	1685.2	2.0878	1.3988	3.5153	79.9043
0.1049	1004.2	1687.8	2.1215	1.3992	3.4957	80.9401
			318 K			
0	973.1	1624.0	1.4043	0.9731	3.8965	-
0.0105	973.3	1626.8	1.4239	0.9733	3.8823	73.8539
0.0209	975.6	1629.6	1.4475	0.9756	3.8598	76.6229
0.0315	977.8	1633.2	1.4710	0.9778	3.8342	79.5672
0.0419	980.4	1636.2	1.4934	0.9804	3.8100	80.5406
0.0525	982.8	1640.4	1.5200	0.9828	3.7812	82.2282
0.0630	985.2	1643.6	1.5476	0.9852	3.7574	83.7629
0.0734	987.8	1646.4	1.5721	0.9878	3.7347	84.4103
0.0839	989.8	1649.6	1.5948	0.9898	3.7127	87.1643
0.0944	992.1	1653.2	1.6216	0.9921	3.6880	88.6576
0.1049	994.2	1656.0	1.6446	0.9942	3.6678	90.7060

Table 2 shows the Limiting Apparent Molal Volume (ϕ_v^o), Experimental Slope (S_v), Limiting Apparent Molal Compressibility (ϕ_K^o), Experimental Slope (S_K), Falkenhagen Coefficient (A) and Jones-Dole Coefficient (B) of Lactose with (DMF-H_2O)+NaCl System at 298, 308 and 318 K.
Apparent molal volumes values increases with concentration of lactose due to the electrostriction effect. The positive values of ϕ_v^o indicates the presence of stronger solute-solvent interactions.

Table 2: Limiting Apparent Molal Volume (ϕ_v^o), Experimental Slope (S_v), Limiting Apparent Molal Compressibility (ϕ_K^o), Experimental Slope (S_K), Jones-Dole Coefficient (B) and Falkenhagen Coefficient (A) of Lactose with (DMF-H_2O)+NaCl System at 298, 308 and 318 K

Parameters	T/K=298	T/K=308	T/K=318
ϕ_v^o /(10^{-6} $m^3 \cdot mol^{-1}$)	-18.2246	-15.9110	-5.6240
S_v/$10^{-6}$$m^3 \cdot lt^{1/2} \cdot mol^{-3/2}$)	176.5568	172.9260	171.1241
ϕ_K^o /(10^{-10} $m^2 \cdot N^{-1}$)	3.9373	4.9209	4.6990
S_K/(10^{-10} $N^{-1} \cdot m^{-1} \cdot mol^{-1}$)	-8.6753	-10.2264	-10.2554
A/ ($dm^{3/2} \cdot mol^{-1/2}$)	-1.1329	-1.36903	-1.3933
B/($dm^3 \cdot mol^{-1}$)	2.4816	3.0221	3.0334

The apparent molar volume of lactose with mixed solvent of DMF-H_2O+NaCl as a function of concentration has been determined using following equation:

$$\phi_v = \frac{1000(\rho_o - \rho)}{C\rho\rho_o} + \frac{M}{\rho_o} \quad (1)$$

where ρ and ρ_o are the density of solution and solvent respectively, C is the concentration ($mol \cdot kg^{-1}$) and M is molar mass of solutes (lactose and NaCl). The plots of ϕ_V and $C^{1/2}$ are linear with the Masson's equation.

$$\phi_v = \phi_v^0 + S_v^* \sqrt{C} \quad (2)$$

where limiting partial molar volume ϕ_v^0 was obtained from the intercepts of linear plot of ϕ_v vs. $\sqrt{C}$ using the least square method and S_v is the experimental slope.

The negative values of S_v suggest weak solute-solute interactions.[13] Adiabatic compressibility (β) is given by the relation;

$$\beta = \frac{1}{u^2 \rho} \quad (3)$$

Adiabatic compressibility (β) decrease with concentration due to electrostatic forces of the ions on the surrounding water molecules. As the temperature rises compressibility of solution increase.[14, 15] When lactose is added in the mixed solvent it attracts certain solvent molecules from the bulk solvent molecules due to electrostriction forces. As the solute concentration increases the electrostrictive

forces break the water structure and with close packing structure around the solute molecules, compressibility decreases which is also supported by other researchers.[16] Apparent Molal Compressibility (ϕ_K) has been calculated using the relation as:

$$\phi_K = \frac{1000(\rho_o\beta - \rho\beta_o)}{C\rho\rho_o} + \frac{\beta_o M}{\rho_o} \qquad (4)$$

where β, β_o ρ and ρ_o are the adiabatic compressibility and density of solution and solvent respectively. M is the molar mass of solute.

$$\phi_K = \phi_K^o + S_K\sqrt{C} \qquad (5)$$

ϕ_K is the linear function of concentration and gives values of partial molar compressibility ϕ_K^o and experimental slope S_K. The values of ϕ_K are negative over the entire range of molality and show decrease with rise in concentration of solute at all the temperatures.

The magnitudes of compressibility depend upon electrostriction and throw light on hydrophobic-hydrophilic interactions in solution. The negative value of ϕ_K indicate hydrophobic interactions and loss of structural compressibility due to increased population of H-bonded water molecules.[17] The negative values of S_K indicates weak solute-solute interactions.

The relative viscosity was measured at 298, 308 and 318 K and analysed by the Jones-Dole equation:

$$\frac{\eta}{\eta_o} = \eta_{rel} = 1 + A\sqrt{C} + BC \qquad (6)$$

where η and η_o are the viscosities of the solution and solvent respectively, A is Falkenhagen coefficient and B is Jones-Dole coefficient.

The Falkenhagen coefficient (A) values were observed to be negative which indicate that solute-solute interactions are relatively weak in the solution. Jones-Dole coefficient -B is highly sensitive to the nature of solute-solvent interactions.[18] Positive values of derived viscosity parameter Jones-Dole coefficient -B show structure making tendency and stronger solute-solvent interactions that increase with rise in temperature from 298 to 318 K.

Derived parameters such as apparent molal compressibility (ϕ_K), acoustic impedance (Z), intermolecular free length (L_f), free volume (V_f), internal pressure (π_i), hydration number (n_H) for lactose+NaCl+ (DMF-H_2O) system are shown in **Table-3.**

Specific Acoustic Impedance (Z) is the product of density (ρ) and sound speed (u) and can be estimated as:

$$Z = u\rho \qquad (7)$$

Acoustic impedance is the complex ratio of effective sound pressure at a point to the effective particle velocity at that point. Acoustic impedance increase with increasing concentration of lactose and temperature indicates that molecular interactions are associative in the nature.[19]

Intermolecular free length (L_f) is obtained using the equation:

$$L_f = K_T\sqrt{\beta} \qquad (8)$$

Where K_T is Jacobson and it is temperature dependent constant and is given by (K_T=93.875+0.375T) x10^{-8}

Table-3: Derived Parameters Apparent Molal Compressibility (ϕ_K), Acoustic Impedance (Z), Intermolecular Free Length (L_f), Free Volume (V_f), Internal Pressure (π_i), Hydration Number (n_H) for Lactose+NaCl+ (DMF-H_2O) System at 298, 308 and 318 K

C/ (mol.Kg^{-1})	ϕ_K / (10^{-11} m^2 N^{-1})	Z/ (10^6 Kg m^{-2} s^{-1})	L_f/ (A^0)	V_f / (10^{-8} m^3 mol^{-1})	π_i / (10^9 Pa)	n_H
			298 K			
0	-	1.6864	0.3852	1.0441	2.4029	-
0.0105	-0.0861	1.6910	0.3846	1.0299	2.4096	0.5367
0.0209	-0.2085	1.6981	0.3834	1.0166	2.4187	1.4180
0.0315	-0.3275	1.7057	0.3822	1.0031	2.4279	2.2579
0.0419	-0.4452	1.7140	0.3808	0.9909	2.4372	3.1335
0.0525	-0.5571	1.7226	0.3794	0.9787	2.4461	3.9556
0.0630	-0.6296	1.7292	0.3784	0.9665	2.4541	4.4733
0.0734	-0.7041	1.7364	0.3773	0.9535	2.4641	4.9624
0.0839	-0.7688	1.7434	0.3763	0.9417	2.4726	5.4202
0.0944	-0.8198	1.7496	0.3753	0.9320	2.4783	5.7994
0.1049	-0.8835	1.7574	0.3741	0.9204	2.4878	6.2587
			308 K			
0	-	1.6244	0.4035	1.6325	2.0727	-
0.0105	0.1611	1.6314	0.4022	1.5942	2.0867	1.0148
0.0209	0.0234	1.6380	0.4011	1.5668	2.0974	1.8167
0.0315	-0.0999	1.6445	0.4000	1.5382	2.1093	2.5036
0.0419	-0.2327	1.6522	0.3986	1.5112	2.1207	3.3209
0.0525	-0.3562	1.6601	0.3973	1.4870	2.1312	4.0776
0.0630	-0.4481	1.6668	0.3961	1.4627	2.1416	4.6148
0.0734	-0.5483	1.6745	0.3948	1.4406	2.1517	5.2098
0.0839	-0.6409	1.6823	0.3935	1.4225	2.1598	5.7868
0.0944	-0.6980	1.6881	0.3926	1.3936	2.1728	6.1106
0.1049	-0.7643	1.6949	0.3915	1.3703	2.1841	6.4856
			318 K			
0	-	1.5803	0.4207	2.2847	1.9039	-
0.0105	-0.0697	1.5834	0.4199	2.2567	1.9071	0.5725
0.0209	-0.2068	1.5898	0.4187	2.2184	1.9167	1.4106
0.0315	-0.3433	1.5969	0.4173	2.1834	1.9256	2.2933
0.0419	-0.4682	1.6041	0.4160	2.1509	1.9344	3.0508
0.0525	-0.5971	1.6122	0.4144	2.1131	1.9448	3.9022
0.0630	-0.6973	1.6193	0.4131	2.0729	1.9562	4.5300
0.0734	-0.7877	1.6263	0.4119	2.0398	1.9660	5.0717
0.0839	-0.8611	1.6328	0.4107	2.0120	1.9734	5.5557
0.0944	-0.9419	1.6401	0.4093	1.9782	1.9834	6.0859
0.1049	-1.0000	1.6464	0.4082	1.9512	1.9910	6.4539

The intermolecular free length decreases with increase in the solute concentration which suggest that there is a significant interaction between solute (Lactose and NaCl) and solvent molecules, suggesting a structure promoting behaviour on the addition of solute. These results are also supported by the viscosity data. As the temperature increases it leads to less ordered structure and more spacing between the molecules due to increase in the thermal energy of the system, which causes increase in volume expansion and hence, increase in intermolecular free length.[20-21]

Hydration number (n_H) was calculated by the following relation:

$$n_H = \frac{n_1}{n_2}\left(1 - \frac{\beta}{\beta_o}\right) \qquad (9)$$

where n_1 and n_2 are the number of moles of solvent and solute respectively, β and β_o are the adiabatic compressibility of the solution and solvent respectively.

The hydration number is the number of water molecules rigidly bound to the ions. The positive values of hydration number reveal that there are significant interactions between solute and solvent molecules due to which structural arrangement in the surrounding is affected. In the present case hydration number increase with concentration at all the investigated temperatures. Water molecules are bonded more tightly in the presence of Na^+ ions than pure water molecules, so net positive hydration enhances the structure of solution than pure water. NaCl works as structure maker in the solvent system[22-23].

Free volume is calculated from sound speed (u) and viscosity (η) of solutions using Suryanarayana relation;

$$V_f = \left(\frac{M_{eff}\,u}{K\eta}\right)^{3/2} \qquad (10)$$

Free volume is a free space in which the core molecules can move inside the solution due to the repulsion of neighbouring molecules. The decrease in free volume with rise in concentration and increase with temperature also confirm the ion-solvent interactions[24]. Free volume also gives better insight to understand the structural rearrangement in solutions. Suryanarayana calculated the internal pressure using sound speed, density and viscosity data from the free volume concept on the basis of statistical thermodynamics as;[25]

$$\pi_i = bRT\left(\frac{K\eta}{u}\right)^{\frac{1}{2}} \frac{\rho^{2/3}}{M_{eff}^{7/6}} \qquad (11)$$

Where b is the space packing factor generally 2 for liquids, R is the gas constant, T is absolute temperature and K is a constant equal to 4.28×10^9, independent of temperature for all type of liquids. M_{eff} is the effective molecular weight.Internal pressure decreases with rise in temperature because of the thermal agitation of ions from each other due to increasing thermal energy, which reduces the possibility of interactions and reduces the cohesive forces and ultimately leads to a decrease in the internal pressure[26]. The derived parameters such as Rao's constant (R_m), relative association (R_A), Wada's constant (W), acoustic relaxation time (τ), absorption coefficient (α/f^2), molar refractivity (R_D) and Gibbs free energy (ΔG) are given in **Table-4.**

Table – 4: Derived Parameters Rao's Constant (R_m), Wada's constant (W), Acoustical Relaxation Time (τ), Absorption coefficient (α/f^2), Molar Refractivity (R_D), Gibbs free energy (ΔG) for Lactose with (DMF-H_2O)+NaCl System at 298, 308 and 318 K

C/ (mol.Kg^{-1})	R_m / (10^{-4}m^5 N^{-1})	R_A	W/ (10^{-4}m^{4}S^{-1})	τ/ (10^{-12} S)	(α/f^2)/ (10^{-15})	R_D/ (10^{-6} m^3 mol^{-1})	ΔG/ (10^{-21} J.mol^{-1})
			298 K				
0	3.5094	-	6.6191	1.1523	1.3473	7.1866	8.0907
0.0105	3.5181	1.0018	6.6368	1.1643	1.3603	7.2468	8.1292
0.0209	3.5236	1.0034	6.6490	1.1734	1.3684	7.2557	8.1614
0.0315	3.5287	1.0054	6.6603	1.1825	1.3764	7.2609	8.1930
0.0419	3.5337	1.0071	6.6715	1.1903	1.3823	7.2699	8.2202
0.0525	3.5388	1.0090	6.6829	1.1981	1.3880	7.2758	8.2469
0.0630	3.5450	1.0107	6.6960	1.2075	1.3966	7.2853	8.2761
0.0734	3.5487	1.0130	6.7051	1.2173	1.4060	7.2936	8.3086
0.0839	3.5541	1.0148	6.7170	1.2266	1.4144	7.3065	8.3378
0.0944	3.5611	1.0163	6.7315	1.2345	1.4212	7.3172	8.3644
0.1049	3.5655	1.0182	6.7416	1.2434	1.4288	7.3269	8.3931
			308 K				
0	3.5976	-	6.7615	0.8881	1.0586	7.2868	7.3952
0.0105	3.6066	1.0014	6.7797	0.9019	1.0728	7.3373	7.4587
0.0209	3.6121	1.0032	6.7918	0.9117	1.0826	7.3460	7.4949
0.0315	3.6166	1.0053	6.8023	0.9223	1.0937	7.3516	7.5313
0.0419	3.6219	1.0071	6.8141	0.9320	1.1027	7.3572	7.5668
0.0525	3.6269	1.0090	6.8252	0.9406	1.1106	7.3619	7.5930
0.0630	3.6323	1.0108	6.8372	0.9503	1.1201	7.3722	7.6267
0.0734	3.6366	1.0129	6.8472	0.9587	1.1279	7.3794	7.6525
0.0839	3.6418	1.0147	6.8589	0.9655	1.1334	7.3930	7.6756
0.0944	3.6480	1.0162	6.8720	0.9786	1.1471	7.4119	7.7184
0.1049	3.6525	1.0183	6.8824	0.9888	1.1574	7.4238	7.7535
			318 K				
0	3.5995	-	6.7646	0.7296	0.8875	7.3285	6.9129
0.0105	3.6149	0.9996	6.7931	0.7371	0.8951	7.3804	6.9512
0.0209	3.6204	1.0014	6.8052	0.7449	0.9031	7.3890	6.9978
0.0315	3.6269	1.0029	6.8188	0.7520	0.9096	7.3967	7.0414
0.0419	3.6314	1.0050	6.8293	0.7586	0.9160	7.4014	7.0565
0.0525	3.6375	1.0066	6.8423	0.7663	0.9229	7.4092	7.1072
0.0630	3.6428	1.0084	6.8541	0.7753	0.9319	7.4169	7.1584
0.0734	3.6471	1.0105	6.8642	0.7828	0.9393	7.4231	7.1944
0.0839	3.6539	1.0119	6.8783	0.7895	0.9454	7.4387	7.2314
0.0944	3.6598	1.0135	6.8911	0.7974	0.9528	7.4504	7.2711
0.1049	3.6659	1.0151	6.9041	0.8043	0.9594	7.4652	7.3089

Rao's constant can be calculated using the following relation:

$$R_m = \frac{M}{\rho}(u)^{1/3} \tag{12}$$

Wada's constant (W) can be calculated using the following equation:

$$W = \frac{M_{eff}}{\rho}\beta^{-\frac{1}{7}} \tag{13}$$

Rao's constant or molar sound velocity shows increase with concentration and temperature. The increasing trends of molar sound velocity, Wada's constant and molar compressibility[27] with concentration suggest the availability of more number of components in a given region thus leads to a close packing of the medium and thereby increase the interactions.

Relative association (R_A) can be determined as:

$$R_A = \left(\frac{\rho}{\rho_o}\right)\left(\frac{u_o}{u}\right)^{1/3} \tag{14}$$

Relative association (R_A) values increase with concentration of lactose in DMF-H_2O+NaCl mixed solvent system. The relative association depends on the solvation of solute molecules and breaking up of the solvent structure by the addition of lactose. The increase of R_A with concentration suggests that solvation of solutes effective over the breaking of the solvent structures.[28]

Acoustic relaxation time (τ) is calculated using the following relation:

$$\tau = \left(\frac{4\eta}{3\rho u^2}\right) \tag{15}$$

Acoustical relaxation time indicates the presence of interactions by addition of lactose.

Gibbs free energy is calculated from acoustic relaxation time (τ) following Eyring rate process theory:

$$\Delta G = RT \ln\left(\frac{kT\tau}{h}\right) \tag{16}$$

where *R* is the gas constant, *k* is the Boltzmann's constant (1.23×10^{-23} J·K^{-1}), T is absolute temperature, h is Planck's constant ($6{\cdot}62\times10^{-34}$ J·s) and τ is the relaxation time.

The Gibbs free energy reveals closer packing of the molecules due to the H-bonding of unlike molecules in the solutions. The decrease in Gibbs free energy (ΔG) with rise in temperature suggest that less time is required for the cooperative process or the rearrangement of molecules in the solution decreases the energy that leads dissociation.[29]

Absorption coefficient (α/f^2) is calculated from the following equation:

$$\alpha = \frac{\omega^2 \tau}{2u} \qquad \text{Where } \omega = 2\pi f$$

$$\frac{\alpha}{f^2} = \frac{4\pi^2 \tau}{2u} \qquad (17)$$

where τ is acoustical relaxation time, π is a constant (22/7), f is frequency and u is speed of sound. The values of absorption coefficient decreases with rise in the temperature and increases with increase in the concentration which also indicates that interaction decreases with temperature but increases with concentration[30].

The molar refractivity, R_D of the mixture can be calculated from the values of refractive indices (n_D) by using the Lorentz-Lorentz equation:

$$R_D = \left[\frac{n_D^2 - 1}{n_D^2 + 2}\right]\left(\sum \frac{x_i M_i}{\rho}\right) \qquad (18)$$

where x_i is the mole fraction and M_i is the molecular weight of the ith components of mixture
The values of refractive index and molar refractivity rise with increase in concentration which exhibit increased interactions. Molar refractivity decreases with rise in the temperature [31].

CONCLUSION

Positive B-coefficient value indicates structure making tendency of lactose in the mixed DMF-H_2O+NaCl system. Solute-solvent interactions increase with temperature due to increased kinetic energy of molecules. Solute-solvent interactions are present in the system which may be due to the formation of hydrogen bonds among the unlike molecules viz. amide group of N,N-dimethylformamide, water molecules, and –OH group of lactose sugars.

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