

Interactions of Cetyltrimethylammonium Bromide with 1,3-Dioxolane in Water: A Study of Viscosity and Volumetric Properties

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Densities and viscosities of ternary mixtures containing cetyltrimethyl ammonium bromide (CTAB) in aqueous solution of 1,3-dioxolane have been measured at 5 K intervals from 298.15 to 313.15 K and at atmospheric pressure. The experimental results of viscosity and density have been analyzed by using Jones-Dole equation and Masson equation. The values of constants A and B of Jones-Dole equation have been interpreted in terms of solute-solute and solute-solvent interactions. The standard partial molar volume, V_{ϕ}^0 at infinite dilution were determined from Masson equations. The structure making/breaking capacity of solute is interpreted with the help of Helper equation. The positive value of Helper's constant $(\partial^2 V_{\phi}^0 / \partial T^2)_p$, and the negative value of dB/dT shows that CTAB in studied organic solvent predominantly acts as a structure-maker.

Keywords: 1,3-Dioxolane, Cetyltrimethylammonium bromide, Ion-solvent interactions, Jones-Dole equation.

INTRODUCTION

Apparent molar volume and viscosity provide useful information about various types of interactions as well as the geometrical effects occurring in solutions. These studies are helping to characterize the structure and properties of solution [1-3]. In recent years, considerable attentions have been given to study the behaviour of salts in various binary solvents [4-7]. Thermodynamic properties of non-polar solutes in water were interpreted by Frank and Evan [8] in terms of ordering of water molecules around the solute. The bulky nature of tetraalkylammonium halide can orient water molecules around them depending on the alkyl chain. Tetraalkylammonium salts can give a better understanding about the influence of electrostatic and hydrophobic interactions on the stability of vitamins, synthesis of gold and silver nanoparticles. It is due the fact that these salts impact the macromolecular conformations by decreasing inter and intra, charge-charge interactions by affecting hydrophobic interactions through the side chains of the salt. A polar solute in water reveals a tendency to aggregate "hydrophobic interaction", which imposes order or built iceberg formation known as structure promoter and which decreases the order known

as structure breaker. CTAB is a cationic detergent widely used in the isolation of DNA protocols. Just like other detergents it can help to disrupt cell membranes. CTAB can binds the polysaccharides that coprecipitate with DNA so its use is more important than other surfactants. 1,3-Dioxolane is a good aprotic solvent for use in preparations, in preparation methods or even as a reactant itself. Because of its small size, it has the ability to dissolve rapidly polar polymers like epoxides, polyesters, urethanes, *etc.* It can be used as an ingredient for some industrial polymers, pharmaceutical intermediates, textiles, metal working and electroplating, lithium batteries, *etc.*

This paper is concerned with the relation between these structural ideas and to investigate the interactions of CTAB with 1,3-dioxolane as both of these are used for human beings. Therefore, in this work, the volumetric properties of CTAB in water as well as in an organic solvent like 1,3-dioxolane have been investigated. Apparent molar volume (V_{ϕ}) and viscosity of CTAB were determined at $T = (298.15-313.15)$ K and used to estimate standard partial molar volume (V_{ϕ}^0), standard partial molar isobaric expansivity (E_{ϕ}^0), Helper's constant $((\partial^2 V_{\phi}^0 / \partial T^2)_p)$. From these values, we can estimate the structure making or structure breaking nature of the molecule in a given solution.

The positive value of Helper's constant will inform about the structure making property and negative value gives the structure breaking property of the solute in solution. Further the values of constants A and B of Jones-Dole equation were estimated. The viscosity B-coefficients of CTAB in aqueous as well as in non-aqueous solutions are hardly determined. The viscosity B-coefficients and partial molar volume of a solute reflects the collective effects of the solute-solvent and solute-solute interactions. Experimental results of viscosity measured in large concentration of electrolytes in aqueous solutions and the solvent-solvent interaction are available in the literature [9-11]. However, only limited numbers of experimental viscosity data of electrolytes in very low concentrated solution in non-aqueous solvents are available. All of the parameters were used to interpret various solute-solute and solute-solvent interactions occurring between the components in ternary mixtures.

EXPERIMENTAL

Chemicals *viz.* cetyltrimethylammonium bromide (CTAB) and 1,3-dioxolane used were purchased from Sigma-Aldrich with 99 % purity. These were further purified by standard methods [12]. The conductivity water and 1,3-dioxolane were mixed to give 0, 10, 20, 30 (v/v) % mixtures, which served as solvent. CTAB was dried over anhydrous CaCl₂ in desiccators before use [13].

Apparatus and procedure: Solutions of concentration 0.06, 0.08, 0.1, 0.12 mol/dm³ were prepared by weighing the required amount of CTAB in a weighing bottle and then dissolving it in required amount of solvent in a 250 mL measuring flask. Rest of solutions of concentration 0.001, 0.005, 0.01, 0.02, 0.04 mol/dm³ were obtained by dilution. Electronic balance of model ABJ-220-4NM (KERN, Germany) was used to record the masses of solute and solvents with a precision of ± 0.01 mg. The density (ρ) of mixture solutions were measured with Rudolph DDM 2911 laboratory density meter. It was calibrated with the samples provided by the manufacturer to confirm the accuracy of the measurement. The uncertainty in density measurements was determined to be 0.00125 g cm⁻³. The molarity of solutions was converted to molality using standard expressions [14,15] and density values. The ultrasonic velocity of solutions were measured with ultrasonic interferometer, model-M-84 (Mittal Enterprises, India,) with a frequency of 2 MHz. Uncertainty in ultrasonic velocity measurements were precise to 0.1 m s⁻¹. The instrument was calibrated with triply distilled water. The temperature of the test liquids were maintained at T = 298.15 to 313.15 K to an accuracy of ± 0.01 K.

Viscosity was determined with U shaped Ostwald viscometer with sufficiently long reflux time more than 200 s to avoid kinetic energy correction. The viscosity was averaged from three readings for each solution. The average of triplet measurements has been taken into account. The measurement of viscosity was carried out in a thermostatic water bath. The uncertainty in the viscosity was found to be less than 0.1 %. The viscosity of pure water at 298.15 K was taken to be 0.890 × 10⁻³ kg m⁻¹ s⁻¹ [16].

RESULTS AND DISCUSSION

Viscosity study: Viscosity of CTAB solution having concentrations 0.001 to 0.12 mol/dm³ in pure water as well as in

1,3-dioxolane-water was studied at different temperatures (298.15 to 313.15 K). The viscosity was determined from the formula: $\eta/\eta_0 = (t \times \rho) / (t_0 \times \rho_0)$; where η , t , ρ are the absolute viscosity, time and density of solution, while η_0 , t_0 and ρ_0 are same quantity for the solvent, respectively. The density and relative viscosity of solutions are shown in Table-1. According to Jones-Dole [17] equation, the relative viscosity varies with concentration c mol dm⁻³ as given:

$$\eta_r = \frac{\eta}{\eta_0} = 1 + A\sqrt{c} + Bc \quad (1)$$

The constant A is the Falkenhagen coefficient which is related to the long range interionic forces [18,19], and the term $Ac^{1/2}$ is predominant in very dilute solutions. The coefficient B is related to the interaction between the ions and solvent and is interpreted as a measure of the structure-making/breaking capacity of an electrolyte in solutions [20]. Jones-Dole parameters were derived by fitting the experimental data to the following equations:

$$\left(\frac{\eta}{\eta_0} - 1 \right) = \eta_{sp} = Ac^{1/2} + Bc \quad (2)$$

$$\frac{\left(\frac{\eta}{\eta_0} - 1 \right)}{\sqrt{c}} = A + B\sqrt{c} \quad (3)$$

The values of constants A and B of Jones-Dole equation obtained from the intercept and slope of plot $(\eta_r - 1)/\sqrt{c}$ versus \sqrt{c} are shown in Table-2 and graphically represented in Fig. 1. The variation of $\eta_{sp}/c^{1/2}$ with molarities 'c' shows that viscosity decreases and the relative viscosity (η_r) increases with the increase in temperature.

The increase in concentration of CTAB causes an increase in force of attractions between the molecules, which tend to stick together and result an increase in viscosity of solutions. The values of A coefficient are found to be positive for CTAB at all temperature indicating the presence of significant ion-ion interactions. The ion-solvent interactions in terms of B coefficient of Jones-Dole equation can be explained on the basis of Stokes and Mills equation [21]. The coefficient B has two contributions: one is negative and other is positive. The positive contribution comes from the tendency of ionic liquid to attract the water molecule, while the negative contribution comes from the fact that the structure of water molecule itself goes against this tendency. Table-2 shows the positive value of B-coefficient, producing an increase in the viscosity of solution with respect to that of pure H₂O. The B-coefficient is positive throughout all experimental temperatures, indicating a structure-making behavior of ionic liquid. The negative value of thermal coefficient (dB/dT) indicates the existence of strongest ion-solvent interactions in the lower temperature [22]. These are in identical agreement with the conclusion drawn from Helper equation [23].

Apparent molar volume: The volumetric properties of solutions are important to study the essential characteristics of ion-solvent and ion-ion interactions exist in solutions. The apparent molar volume (V_ϕ) of a solution is nothing but the change in its volume per unit mole of solute in solvent. The

TABLE-1
DENSITY (ρ), APPARENT MOLAR VOLUME (V_ϕ) AND RELATIVE VISCOSITY (η_r) OF CTAB IN PURE WATER AND 10-30 %
1,3-DIOXOLANE + WATER SOLUTIONS AT ($T = 298.15$ TO 313.15 K) AND AT ATMOSPHERIC PRESSURE, $p = 0.1$ MPa

m_A (mol kg^{-1})	$\rho \times 10^{-3}$ (kg m^{-3})				$V_\phi \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)				η_r			
	298.15 K	303.15 K	308.15 K	313.15 K	298.15 K	303.15 K	308.15 K	313.15 K	298.15 K	303.15 K	308.15 K	313.15 K
CTAB in pure water												
0.000	0.99707	0.99562	0.99415	0.99228	–	–	–	–	1.0000	1.0000	1.0000	1.0000
0.001	0.99717	0.99569	0.99421	0.99235	–	–	–	–	1.0222	1.0239	1.0260	1.0282
0.005	0.99732	0.99589	0.99442	0.99258	315.32	312.45	310.83	306.38	1.0527	1.0564	1.0609	1.0657
0.010	0.99744	0.99603	0.99457	0.99278	328.44	324.85	323.29	316.47	1.0776	1.0828	1.0893	1.0960
0.020	0.99761	0.99623	0.99477	0.99304	338.56	335.52	334.81	328.93	1.1156	1.1233	1.1328	1.1415
0.041	0.99789	0.99652	0.99510	0.99341	344.96	343.44	342.61	339.15	1.1761	1.1868	1.1997	1.2130
0.061	0.99810	0.99672	0.99534	0.99373	348.30	347.64	346.74	343.25	1.2273	1.2404	1.2553	1.2723
0.082	0.99830	0.99694	0.99559	0.99401	350.14	349.40	348.80	345.96	1.2725	1.2894	1.3057	1.3255
0.103	0.99848	0.99715	0.99582	0.99430	351.36	350.59	350.20	347.55	1.3175	1.3362	1.3532	1.3757
0.125	0.99863	0.99734	0.99606	0.99458	352.44	351.65	351.11	348.64	1.3596	1.3797	1.3992	1.4247
CTAB in 10 % 1,3-dioxolane												
0.000	1.01356	1.01293	1.01235	1.01168	–	–	–	–	1.021	1.019	1.026	1.026
0.001	1.01359	1.01298	1.01241	1.01176	335.58	330.52	326.38	320.50	1.025	1.029	1.032	1.035
0.005	1.01364	1.01305	1.01248	1.01182	340.47	337.26	334.05	330.84	1.059	1.066	1.074	1.080
0.010	1.01371	1.01312	1.01256	1.01189	344.83	342.59	340.36	338.12	1.087	1.097	1.108	1.116
0.020	1.01377	1.01321	1.01266	1.01200	349.29	347.18	345.07	342.96	1.128	1.143	1.157	1.170
0.041	1.01387	1.01334	1.01281	1.01218	352.04	350.56	349.09	347.62	1.191	1.214	1.233	1.251
0.061	1.01397	1.01348	1.01296	1.01233	353.32	351.78	350.54	349.05	1.247	1.274	1.297	1.319
0.082	1.01408	1.01358	1.01310	1.01248	354.26	352.84	351.42	350.00	1.297	1.329	1.355	1.380
0.103	1.01419	1.01369	1.01326	1.01265	354.69	353.40	352.11	350.64	1.345	1.378	1.408	1.437
0.125	1.01430	1.01382	1.01341	1.01282	354.85	353.61	352.38	351.14	1.392	1.425	1.460	1.488
CTAB in 20 % 1,3-dioxolane												
0.000	1.01852	1.01789	1.01731	1.01658	–	–	–	–	1.009	1.017	1.018	1.022
0.001	1.01855	1.01792	1.01736	1.01663	328.3	324.0	321.4	317.9	1.029	1.032	1.035	1.038
0.005	1.01864	1.01802	1.01745	1.01673	337.8	334.0	330.8	328.6	1.067	1.074	1.081	1.088
0.010	1.01870	1.01809	1.01754	1.01682	342.2	340.0	336.9	335.7	1.097	1.107	1.118	1.127
0.020	1.01876	1.01817	1.01764	1.01694	346.8	345.0	342.6	341.0	1.143	1.158	1.172	1.185
0.041	1.01886	1.01830	1.01780	1.01714	349.8	348.6	347.0	345.5	1.214	1.234	1.254	1.274
0.061	1.01890	1.01837	1.01790	1.01727	351.2	350.0	348.6	347.1	1.273	1.298	1.322	1.347
0.082	1.01897	1.01848	1.01805	1.01746	352.2	350.8	349.6	348.3	1.328	1.355	1.383	1.412
0.103	1.01905	1.01858	1.01817	1.01760	352.8	351.4	350.3	349.0	1.378	1.407	1.441	1.472
0.125	1.01914	1.01870	1.01831	1.01777	353.3	351.9	350.8	349.8	1.424	1.459	1.494	1.527
CTAB in 30 % 1,3-dioxolane												
0.000	1.02338	1.02277	1.02229	1.02174	–	–	–	–	1.016	1.018	1.024	1.024
0.001	1.02341	1.02279	1.02232	1.02175	331.0	323.6	320.5	314.8	1.031	1.034	1.038	1.042
0.005	1.02351	1.02289	1.02241	1.02186	335.8	331.2	329.4	326.9	1.072	1.080	1.088	1.096
0.010	1.02358	1.02296	1.02248	1.02193	340.2	337.9	335.9	333.4	1.105	1.115	1.127	1.139
0.020	1.02365	1.02306	1.02255	1.02205	344.7	343.3	341.4	339.1	1.153	1.169	1.185	1.201
0.041	1.02374	1.02317	1.02268	1.02219	348.3	347.2	346.0	344.8	1.228	1.250	1.273	1.296
0.061	1.02380	1.02326	1.02280	1.02234	349.4	348.5	347.3	346.1	1.291	1.318	1.345	1.374
0.082	1.02387	1.02336	1.02293	1.02247	350.3	349.3	348.3	347.0	1.348	1.379	1.409	1.442
0.103	1.02395	1.02346	1.02306	1.02261	350.9	350.1	349.1	347.7	1.401	1.434	1.468	1.504
0.125	1.02402	1.02354	1.02319	1.02275	351.4	350.6	349.7	348.4	1.450	1.487	1.523	1.562

m_A is the molality of CTAB in the (water + 1,3-dioxolane). Standard uncertainties, u are $u(T) = 0.01$ K, $u(p) = 0.01$ MPa, $u(\rho) = 3 \times 10^{-6}$ g cm^{-3} and $u(m) = 2 \times 10^{-5}$ mol kg^{-1} .

apparent molar volume (V_ϕ , $\text{m}^3 \text{mol}^{-1}$), of CTAB in aqueous 1,3-dioxolane solutions have been computed from the values of density at different temperature, $T = (298.15$ to $313.15)$ K using the following equation:

$$V_\phi = \frac{M_1}{\rho} + \frac{(\rho^0 - \rho)}{m_A \rho \rho^0} \quad (4)$$

where, m_A (mol kg^{-1}) is the molality, M_1 (kg mol^{-1}) is the molar mass of CTAB, ρ (kg m^{-3}) and ρ^0 (kg m^{-3}) are the density of solution and pure solvent, respectively. The values of V_ϕ (m^3

mol^{-1}) are reported in Table-1. It has been found that V_ϕ values are all large positive and increase with increasing mass fraction of CTAB and decrease with increasing temperature of solutions.

The standard partial molar volume, V_ϕ^0 ($\text{m}^3 \text{mol}^{-1}$), can also be calculated using Masson-type equation [24] as follows:

$$V_\phi = V_\phi^0 + S_V \sqrt{m_A} \quad (5)$$

The values of V_ϕ^0 and the coefficients S_V at $T = 298.15$ - 313.15 K are given in Table-2. The variation of standard partial molar volume and viscosity B coefficient with temperature are plotted in Fig. 2.

TABLE-2
LIMITING APPARENT MOLAR VOLUME (V_ϕ^0) AND EXPERIMENTAL SLOPE (S_v), VISCOSITY B-COEFFICIENTS
AND A VALUES OF CTAB IN 0-30 % 1,3-DIOXOLANE-WATER AT (T = 298.15-313.15 K)

Solvent (v/v %)	T = 298.15 K			T = 303.15 K			T = 308.15 K			T = 313.15 K		
	$10^6 V_\phi^0$ (m^3 mol^{-1})	$10^6 S_v$ ($\text{m}^{3/2}$ $\text{mol}^{-3/2}$)	$\sigma \times 10^6$	$10^6 V_\phi^0$ (m^3 mol^{-1})	$10^6 S_v$ ($\text{m}^{3/2}$ $\text{mol}^{-3/2}$)	$\sigma \times 10^6$	$10^6 V_\phi^0$ (m^3 mol^{-1})	$10^6 S_v$ ($\text{m}^{3/2}$ $\text{mol}^{-3/2}$)	$\sigma \times 10^6$	$10^6 V_\phi^0$ (m^3 mol^{-1})	$10^6 S_v$ ($\text{m}^{3/2}$ $\text{mol}^{-3/2}$)	$\sigma \times 10^6$
0	316.1 ± 4.70	115.8 ± 20.10	5.57	312.1 ± 4.80	126.4 ± 2.20	5.60	310.4 ± 4.90	130.2 ± 20.80	5.70	303.6 ± 4.70	143.0 ± 19.8	5.40
10	348.4 ± 0.79	19.0 ± 2.70	0.33	346.5 ± 0.69	20.8 ± 2.40	0.28	344.9 ± 4.90	21.9 ± 2.40	0.29	343.1 ± 0.53	23.2 ± 1.80	0.22
20	345.3 ± 0.61	23.1 ± 2.10	0.25	344.3 ± 0.48	22.0 ± 1.70	0.20	342.6 ± 0.61	24.9 ± 2.10	0.26	341.1 ± 0.42	27.8 ± 1.40	0.18
30	344.1 ± 0.32	20.9 ± 1.10	0.14	342.7 ± 0.32	22.9 ± 1.30	0.16	341.1 ± 0.31	24.6 ± 1.11	0.13	340.1 ± 0.26	23.8 ± 0.92	0.11
Solvent (v/v %)	$10^3 A$ (m^3 $\text{mol}^{-1/2}$)	$10^3 B$ (m^3 mol^{-1})	$\sigma \times 10^3$	$10^3 A$ (m^3 $\text{mol}^{-1/2}$)	$10^3 B$ (m^3 mol^{-1})	$\sigma \times 10^3$	$10^3 A$ (m^3 $\text{mol}^{-1/2}$)	$10^3 B$ (m^3 mol^{-1})	$\sigma \times 10^3$	$10^3 A$ (m^3 $\text{mol}^{-1/2}$)	$10^3 B$ (m^3 mol^{-1})	$\sigma \times 10^3$
0	675.04 ± 1.84	969.64 ± 8.2	0.003	726.37 ± 9.2	958.4 ± 4.1	0.001	794.29 ± 2.5	946.75 ± 11.1	0.951	85964 ± 1.2	935.1 ± 5.4	0.002
10	773.67 ± 3.53	950.04 ± 15.8	0.005	880.46 ± 1.74	940.61 ± 7.7	0.003	988.89 ± 2.8	926.8 ± 12.8	0.004	1077.27 ± 1.7	913.7 ± 7.7	0.003
20	884.67 ± 1.32	933.41 ± 5.9	0.002	993.61 ± 1.3	921.61 ± 5.9	0.002	1092.7 ± 0.94	907.8 ± 4.2	0.001	1196.53 ± 1.3	894.6 ± 5.6	0.002
30	963.6 ± 1.53	922.92 ± 6.8	0.002	1070.7 ± 1.9	908.4 ± 8.6	0.003	1201.82 ± 0.61	895.0 ± 2.7	0.001	1315.48 ± 2.2	881.5 ± 9.8	0.003

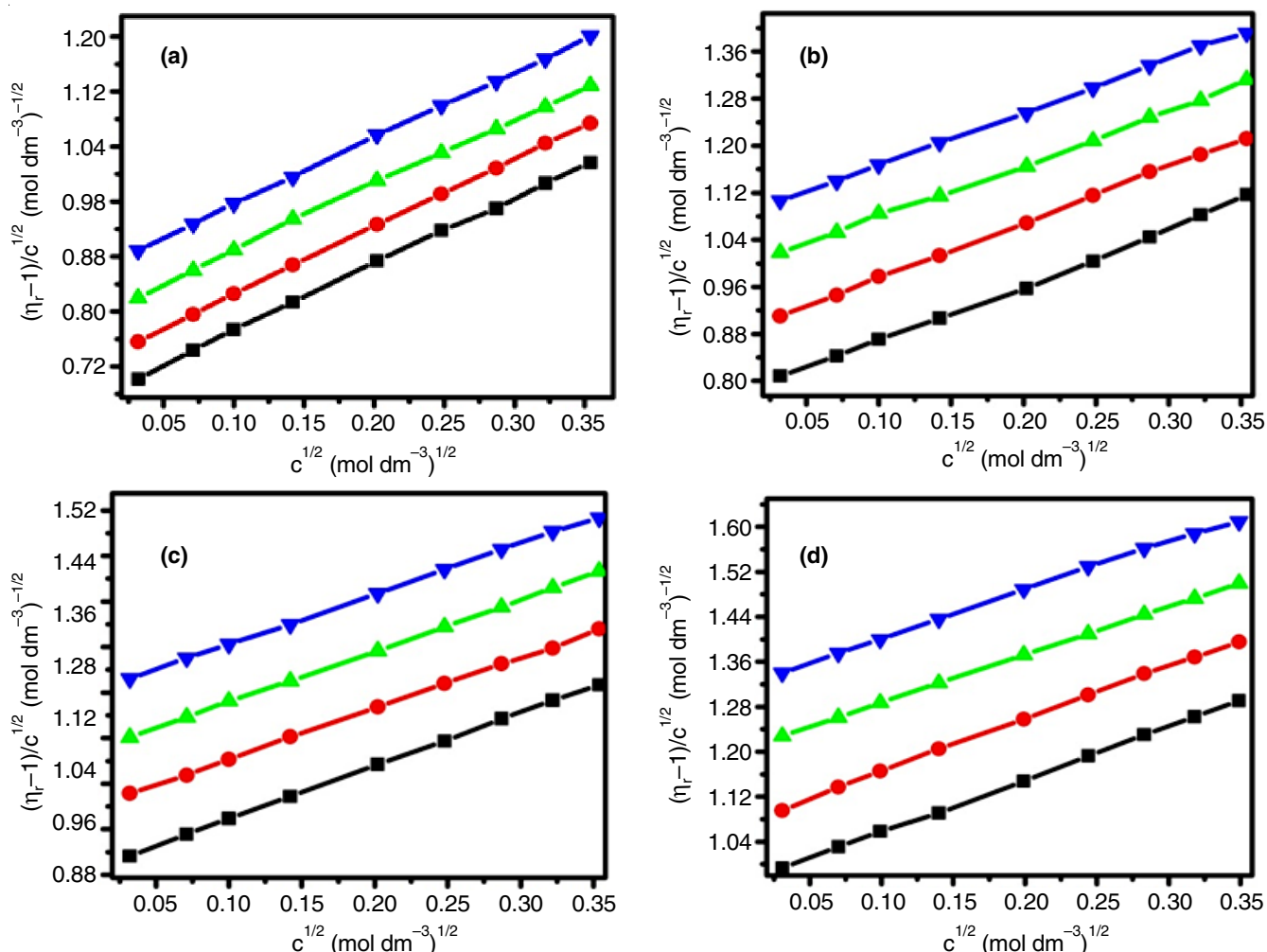


Fig. 1. Plot of $(\eta_r - 1)/c$ vs. \sqrt{c} of CTAB in (a) water, (b) 10 % 1,3-dioxolane-water, (c) 20 % 1,3-dioxolane-water and (d) 30 % 1,3-dioxolane-water, respectively at different temperatures: T = \blacktriangledown — 313.15 K, \blacktriangle — 308.15 K, \bullet — 303.15 K and \blacksquare — 298.15 K, respectively

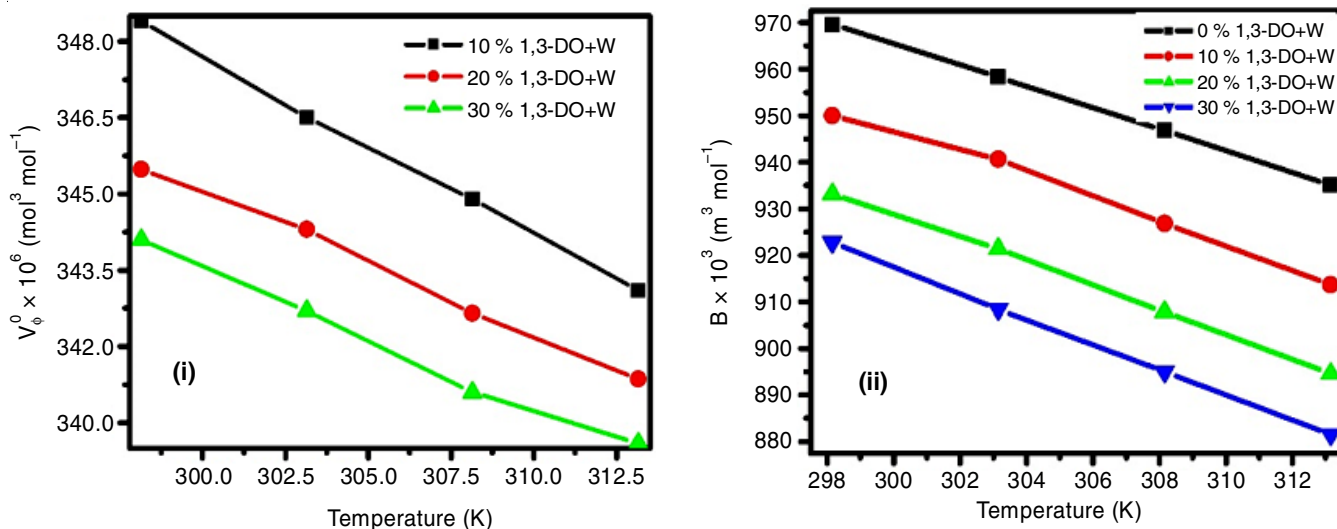


Fig. 2. Plot of partial molar volume (V_{ϕ}^0) (i) and B-coefficient (ii) vs. temperature of CTAB in 1,3-dioxolane (1,3-DO) + water (W)

Effect of temperature on standard partial molar volume:

Additionally, the effect of temperature on standard partial molar volume, V_{ϕ}^0 , can be stated by the equation as follows:

$$V_{\phi}^0 = a_0 + a_1 T + a_2 T^2 \quad (6)$$

where, a_0 , a_1 and a_2 are empirical constants and T (K) is the experimental temperature.

The limiting apparent molar expansivity, E_{ϕ}^0 ($\text{m}^3 \text{mol}^{-1} \text{K}^{-1}$) is an important parameter to study interionic interactions established in different solutions, which can be calculated as follows:

$$E_{\phi}^0 = \left(\frac{\partial V_{\phi}^0}{\partial T} \right)_p = a_1 + 2a_2 T \quad (7)$$

Further, the structure promoting and structure breaking capacity of an ionic liquid in the mixed solutions is determined with the help of Helper equation [23] using eqn 8:

$$\left(\frac{\partial E_{\phi}^0}{\partial T} \right)_p = \left(\frac{\partial^2 V_{\phi}^0}{\partial T^2} \right)_p = 2a_2 \quad (8)$$

The values of empirical constants, a_0 , a_1 and a_2 of eqn. 6, E_{ϕ}^0 and the values of $(\partial E_{\phi}^0 / \partial T)_p$ for CTAB in water and aqueous solutions of 1,3-dioxolane are reported in Table-3.

It can be seen that apparent molar volume at infinite dilution for the investigated solutions of CTAB in aqueous 1,3-dioxolane decreases with increasing both the concentration of 1,3-dioxolane and temperature of solutions. The V_{ϕ}^0 values reported in Table-2 are all large and positive for the investigated liquids. It is understood that the physical properties such as shear viscosity,

density of CTAB depend on the ion solvent interaction of ammonium ion with 1,3-dioxolane and water molecules. Due to the presence of two etherial oxygen 1,3-dioxolane attracts strongly to ammonium ion of CTAB which results in the increase in density, viscosity and decrease in standard partial molar volume (V_{ϕ}^0). At infinite dilution, each ion is surrounded by the solvent molecules and being infinitely distant with other ions. So V_{ϕ}^0 is unaffected by ion-ion interactions and it is only a measure of of the ion-solvent interactions. The V_{ϕ}^0 values of solutions decrease with increase in temperature due to the release of water molecules from the loose hydration layers of CTAB in the solution. This indicates the presence of strong ion-solvent interactions in such solutions in which these types of inteactions are strengthened at low temperatures. The E_{ϕ}^0 values are shown in Table-3. This parameter is a mesure of solute-solvent interactions [25] and solvation behaviour. On heating, some water molecules may be released from hydration layers of solute which decrease the solution volume and cosequently leads to negative E_{ϕ}^0 values [26]. It is found that E_{ϕ}^0 value decrease with increasing temperature, this decrease in E_{ϕ}^0 with temperature shows the presence of caging effect.

The sign of $(\partial^2 V_{\phi}^0 / \partial T^2)_p$ or $(\partial E_{\phi}^0 / \partial T)_p$ value is a better criterion in characterizing the long range structure making and breaking ability of solute in the solution [27]. If $(\partial^2 V_{\phi}^0 / \partial T^2)_p$ value is positive, the solute is structure maker and if its sign is negative, it is structure breaker. In the present case, the positive value of $(\partial^2 V_{\phi}^0 / \partial T^2)_p$ indicates that CTAB predominantly acts as solvent structure maker in aqueous 1,3-dioxolane over the experimental temperature ranges studied.

TABLE-3
VALUES OF EMPIRICAL PARAMETERS OF EQUATION 6 AND LIMITING APPARENT MOLAR EXPANSIBILITIES, E_{ϕ}^0 AND $(\partial E_{\phi}^0 / \partial T)_p$ OF CTAB IN AQUEOUS SOLUTIONS OF 1,3-DIOXOLANE AT ($T = 298.15$ TO 313.15 K) AND AT ATMOSPHERIC PRESSURE, $p = 0.1$ MPa

Solvent (v/v %)	$a_0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)	$a_1 \times 10^6$ ($\text{m}^3 \text{mol}^{-1} \text{K}^{-1}$)	$a_2 \times 10^6$ ($\text{m}^3 \text{mol}^{-1} \text{K}^{-2}$)	$\sigma \times 10^2$	$E_{\phi}^0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1} \text{K}^{-1}$)				$(\partial E_{\phi}^0 / \partial T)_p \times 10^6$ ($\text{m}^3 \text{mol}^{-1} \text{K}^{-2}$)
					298.15 K	303.15 K	308.15 K	313.15 K	
0	1.1283	2.8508	-0.0060	0.224	-0.7389	-0.7991	-0.8593	-0.9195	-0.0120
10	559.2120	-0.8532	0.0004	0.320	-0.6148	-0.6108	-0.6068	-0.6028	0.0008
20	1305.4404	-5.7845	0.0085	2.711	-0.7100	-0.6249	-0.5398	-0.4547	0.0170
30	1641.8853	-8.0194	0.0122	0.033	-0.7445	-0.6225	-0.5005	-0.3785	0.0244

TABLE-4
PARTIAL MOLAR VOLUMES TRANSFER, ΔV_{ϕ}^0 AND VISCOSITY B-COEFFICIENT OF TRANSFER, ΔB FOR CTAB IN
AQUEOUS SOLUTIONS OF 1,3-DIOXOLANE AT (T = 298.15 to 313.15 K) AND AT ATMOSPHERIC PRESSURE, $p = 0.1$ MPa

Solvent (v/v %)	298.15 K		303.15 K		308.15 K		313.15 K	
	$V_{\phi}^0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)	$\Delta V_{\phi}^0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)	$V_{\phi}^0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)	$\Delta V_{\phi}^0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)	$V_{\phi}^0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)	$\Delta V_{\phi}^0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)	$V_{\phi}^0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)	$\Delta V_{\phi}^0 \times 10^6$ ($\text{m}^3 \text{mol}^{-1}$)
0	316.1	0.00	312.1	0.00	310.4	0.00	303.6	0.00
10	348.4	32.30	346.5	34.40	344.9	34.50	343.1	39.50
20	345.5	29.38	344.3	32.20	342.7	32.25	341.4	37.76
30	344.1	28.00	342.7	30.60	341.1	30.70	340.1	36.50
Solvent (v/v %)	$10^3 B$ ($\text{m}^3 \text{mol}^{-1}$)	$10^3 \Delta B$ ($\text{m}^3 \text{mol}^{-1}$)	$10^3 B$ ($\text{m}^3 \text{mol}^{-1}$)	$10^3 \Delta B$ ($\text{m}^3 \text{mol}^{-1}$)	$10^3 B$ ($\text{m}^3 \text{mol}^{-1}$)	$10^3 \Delta B$ ($\text{m}^3 \text{mol}^{-1}$)	$10^3 B$ ($\text{m}^3 \text{mol}^{-1}$)	$10^3 \Delta B$ ($\text{m}^3 \text{mol}^{-1}$)
0	969.6	0.00	958.3	0.00	946.8	0.00	935.1	0.00
10	950.0	-19.64	940.6	-17.69	926.8	-19.92	913.7	-21.32
20	933.1	-36.56	921.4	-36.91	907.8	-38.92	894.6	-40.49
30	922.8	-46.86	908.4	-49.97	895.0	-51.76	881.5	-53.51

Partial molar properties of transfer: Standard partial molar volume of transfer (ΔV_{ϕ}^0) and viscosity B-coefficients of transfer (ΔB) from water to different aqueous 1,3-dioxolane solutions for CTAB at T = 298.15 to 313.15 K, have been estimated by the following formula [28]:

$$\Delta V_{\phi}^0 = V_{\phi}^0(\text{CTAB in aqueous 1,3-dioxolane}) - V_{\phi}^0(\text{in water}) \quad (9)$$

$$\Delta B = B(\text{CTAB in aqueous 1,3-dioxolane}) - B(\text{in water}) \quad (10)$$

The values of ΔV_{ϕ}^0 and ΔB are shown in Table-4. The positive values of ΔV_{ϕ}^0 implies the decrease in the shrinkage volume of water by CTAB in presence of 1,3-dioxolane. This results proposes that 1,3-dioxolane has a dehydration effect on hydrated CTAB. The negative value of ΔB supports the results obtained for ΔV_{ϕ}^0 values.

Conclusion

The measurement of viscosity, density, apparent molar volume of solutions of CTAB in pure water and 1,3-dioxolane-water mixture have been reported at T = 298.15-313.15 K. The results showed that densities increase with increase in concentration of CTAB and decrease with temperature. The B-coefficient for viscosity was positive at all temperatures, indicating the structure making behaviour of CTAB in 1,3-dioxolane and water. The negative value of thermal coefficient (dB/dT) may be due to the strong solute-solvent interactions in the lower temperature. From the apparent molar volumes at infinite dilution, it may be proved the presence of strong solute-solvent interactions. The negative values of E_{ϕ}^0 and the positive values of $(\partial E_{\phi}^0/\partial T)_{\phi}$ of CTAB in aqueous 1,3-dioxolane represent the structure making behaviour of CTAB in studied solutions. The positive values of ΔV_{ϕ}^0 indicate the decrease in the shrinkage volume of water by CTAB in the presence of 1,3-dioxolane.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

- R. Khan, M.A. Uddin and M. Mukhtar, *J. Chem. Eng. Data*, **52**, 1548 (2007); <https://doi.org/10.1021/je060219e>.
- M. Habibullah, K.N. Das, I. Rahman, M.M. Hasegawa, M.A. Uddin and K. Saifuddin, *J. Chem. Eng. Data*, **55**, 5311 (2010); <https://doi.org/10.1021/je100390b>.
- K. Zhou, Y. Chen, J. Chen, G. Bai and J. Wang, *Phys. Chem. Chem. Phys.*, **13**, 14542 (2011); <https://doi.org/10.1039/C1CP20948E>.
- I. Ramakanth and J. Pištora, *RSC Adv.*, **5**, 50306 (2015); <https://doi.org/10.1039/C5RA03478G>.
- M.S. Khan, A.V. Karatrantos, T. Ohba and Q. Cai, *Phys. Chem. Chem. Phys.*, **21**, 22722 (2019); <https://doi.org/10.1039/C9CP03332G>.
- T. Zamir and A. Khan, *J. Pak. Chem. Soc.*, **27**, 130 (2005).
- M.N. Roy, R.K. Das and A. Bhattacharjee, *Russ. J. Phys. Chem. A*, **84**, 2201 (2010); <https://doi.org/10.1134/S0036024410130017>.
- H.S. Frank and M.W. Evans, *J. Chem. Phys.*, **13**, 507 (1945); <https://doi.org/10.1063/1.1723985>.
- P. Jain, S. Sharma and R.K. Shukla, *Phys. Chem. Liq.*, **51**, 547 (2013); <https://doi.org/10.1080/00319104.2012.760084>.
- K. Sharma, S. Chouhan and R. Singh, *J. Chem. Thermodyn.*, **103**, 381 (2016); <https://doi.org/10.1016/j.jct.2016.08.032>.
- S.K. Shah, S.K. Chatterjee and A. Bhattacharjee, *J. Chem.*, **2016**, Article ID 2176769 (2016); <https://doi.org/10.1155/2016/2176769>.
- A. Weissberger, Organic solvents, In: *Technique of Organic Chemistry*, Interscience: N.Y., edn 2, vol. 7 (1955).
- B.B. Nanda, *Indian J. Pure Appl. Phys.*, **54**, 471 (2016).
- B.B. Nanda, B. Nanda and P.C. Mohanty, *J. Mol. Liq.*, **171**, 50 (2012); <https://doi.org/10.1016/j.molliq.2012.03.011>.
- B. Jacobson and P.A. Heedman, *Acta Chem. Scand.*, **7**, 705 (1953); <https://doi.org/10.3891/acta.chem.scand.07-0705>.
- J.A. Dean, *Lange's Hand Book of Chemistry*, McGraw-Hill Book Company, edn 12 (1979).
- G. Jones and M. Dole, *J. Am. Chem. Soc.*, **51**, 2950 (1929); <https://doi.org/10.1021/ja01385a012>.
- H. Falkenhagen and M. Dole, *Phys. Z.*, **30**, 611 (1929).
- H. Falkenhagen and E.L. Vernon, *Philos. Mag.*, **7**, 537 (1932); <https://doi.org/10.1080/14786443209462095>.
- D. Feakins and K. Lawrence, *J. Chem. Soc. A*, 212 (1966); <https://doi.org/10.1039/J19660000212>.
- R.H. Stokes and R. Mills, *The International Encyclopaedia of Physical Chemistry and Chemical Physics*, Pergamon: London, p. 39 (1965).
- M. Huque, I.A. Siddique and M.N. Uddin, *J. Chem. Thermodyn.*, **38**, 1474 (2006); <https://doi.org/10.1016/j.jct.2006.01.002>.
- L.G. Helper, *Can. J. Chem.*, **47**, 4613 (1969); <https://doi.org/10.1139/v69-762>.
- D.O. Masson, *Philos. Mag.*, **8**, 218 (1929); <https://doi.org/10.1080/14786440808564880>.
- H. Shekkaari, S.S. Mousavi and Y. Mansoori, *Int. J. Thermophys.*, **30**, 499 (2009); <https://doi.org/10.1007/s10765-009-0566-6>.
- A. Pal and N. Chauhan, *J. Mol. Liq.*, **149**, 29 (2009); <https://doi.org/10.1007/s10953-010-9620-z>.
- H. Shekkaari, Y. Mansoori and R. Sadeghi, *J. Chem. Thermodyn.*, **40**, 852 (2008); <https://doi.org/10.1016/j.jct.2008.01.003>.
- C. Zhao, P. Ma and J. Li, *J. Chem. Thermodyn.*, **37**, 37 (2005); <https://doi.org/10.1016/j.jct.2004.07.030>.