Asian Journal of Chemistry; Vol. 36, No. 9 (2024), 2153-2159

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2024.32211

Physico-Chemical Studies of Anionic Surface Active Ionic Liquid in Aqueous Poly(vinyl pyrrolidone) (PVP) Solutions: Density and Speed of Sound Measurements

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Received: 3 June 2024; *Accepted*: 7 August 2024; *Published online*: 30 August 2024; AJC-21742

Density (ρ) and speed of sound (u) values were measured for environmentally safer surface active ionic liquid (SAIL) tetrabutylammonium dodecylsulphate (TBADS) in 0.0, 0.1 and 0.3% w/w [PVP] at various temperatures (293.15-313.15 K). The volumetric and acoustic parameters such as isentropic compressibility (κ_s), apparent molar volume (V_ϕ) and compressibility ($\kappa_{s,\phi}$), intermolecular free length (L_f), relative association (RA), specific acoustic impedance (Z) and molar sound number ([U]) were calculated by utilizing density and speed of sound values. These parameters were valuable to understand the interactions accessible in TBADS-PVP-water system. The existence of hydrophilic/hydrophobic interactions for TBADS in aqueous PVP solution was suggested by the variations in volumetric parameters, which further supported by various calculated acoustic parameters. The interactional facts may be contemplated as functional tool to enhance the utility of SAIL-polymer in various technological, biomedical and industrial fields.

Keywords: Poly(vinyl pyrrolidone), Tetrabutylammonium dodecylsulphate, Impedance, Interactions.

INTRODUCTION

The non-ionic or uncharged polymers, which are usually soluble in water, have garnered significant interest in various biomedical and industrial applications. Among these, poly-(vinyl pyrrolidone) (PVP) stands out as a biocompatible and non-toxic polymer with a wide range of applications. It has been used as a blood plasma expander to maintain blood fluid levels [1,2], a binder [2], a film-forming and clarifying agent [1,3], a non-viral vector for gene therapy with reduced cyto-toxicity and superior gene transfection efficiency [4,5], a material for bone grafting in tissue engineering to treat various bone defects [6,7], in cosmetic and food industries [1,6], *etc*. Their applicability seems to be enhanced as a result of alteration in phase, rheological and interfacial properties of polymers due to the incorporation of surfactants [8-10]. The binding between polymer and surfactant with opposite charges is mainly influenced by electrostatic interactions, whereas polar groups, hydrophobicity of polymers and surfactant head groups are major contributing factors in the case of non-ionic poly-mers [11,12]. Such polymer-surfactant blend also has a wide range of applications in the industrial as well as pharmaceutical fields like protein solubilization [13], better oil recovery [14], *etc*.

Surface active ionic liquids (SAILs) have interesting feat-ures due to their amphiphilic properties, surface activity, environment friendly nature and better emulsifying tendency than traditional surfactants [15-17]. SAILs have been broadly used for the formation of stabilized aggregates (micelles/vesicles) in the macro/nanoscale due to their biological and tailored physico-chemical properties [17,18]. Such stabilized aggregates of SAILs with tuned properties have made them suitable for utilization in diverse fields like biomolecule stabili-zation [19], oil spill remediation [20], extraction of metal ion and natural products [21,22], hydrocarbon solubilization [23], stabilizer and surface modifier in nanotechnology [15,24,25], ADP/dopamine/ascorbic acid detector [26,27], protecting agents for cultural heritage stones [28], carrier of chemotherapeutic agent [29], *etc*. Their properties can be tailored by multiple combinations of modified cationic and anionic structures of SAILs [11,15,17].

In this study, tetraalkylammonium cation-based SAIL (TBADS) has been utilized because of their superior nature to imidazolium cation based SAILs in terms of low cost, bio-

degradability and toxicity for applications like catalytic conversion of CO_2, hydrocarbon solubilization [30,31], *etc.* The enhancement in the colloidal properties of these SAILs due to the incorporation of polymers increases the applicability in numerous other fields such as medicinal formulation [32], coatings and paints, detergency [8,11], nanomaterial synthesis [33], water treatment plants [34,35], *etc.* Due to such interesting features of these complexes, we have discussed the volumetric/acoustic properties of TBADS in the aqueous solution of PVP by using density and speed of sound measurements.

EXPERIMENTAL

In this work, the surface active ionic liquid (SAIL), tetrabutylammonium dodecylsulphate (TBADS) was synthesized as per reported work [30]. Poly(vinyl pyrrolidone) (PVP 40000) (CAS No. 9003-39-8) was supplied by Sisco Research Laboratories Pvt. Ltd., India.

Density and speed of sound measurements: The density and speed of sound values were measured for TBADS in aqueous solution of PVP (0.0, 0.1 and 0.3% w/w) by using a density and sound analyzer (DSA-5000) instrument supplied by Anton Paar, Austria. The speed of sound was measured with a working frequency of ~3 MHz. The standard uncertainties for density and speed of sound values were 0.08 Kg m^{-3} and 0.2 m s^{-1}, respectively [12,36].

RESULTS AND DISCUSSION

Volumetric and compressibility studies: The experimental values of density (ρ) and speed of sound (u) are shown in Table-1 for TBADS in aqueous PVP solutions (0.0%, 0.1%,

TABLE-1
DENSITY (ρ) VALUES (kg m^{-3}) AND SPEED OF SOUND (u) VALUES (m s^{-1}) FOR TPADS/TBADS IN AQUEOUS PVP SOLUTIONS AT DIFFERENT TEMPERATURES (293.15–313.15 K)

ρ (kg m^{-3})						u (m s^{-1})					
[TBADS] (mmol kg^{-1})	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K	[TBADS] (mmol kg^{-1})	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
0.0% w/w PVP											
0.000	998.213 [37]	997.045 [37]	995.646 [37]	994.024 [37]	992.203 [37]	0.000	1482.61 [37]	1496.70 [37]	1509.07 [37]	1519.70 [37]	1528.83 [37]
0.222	997.731	995.689	993.415	990.740	987.265	0.222	1483.76	1497.63	1509.98	1520.79	1530.07
0.444	998.274	997.160	995.765	994.141	992.318	0.444	1484.07	1498.18	1510.63	1521.51	1530.72
0.666	998.284	997.155	995.754	994.091	992.187	0.666	1484.30	1498.26	1510.48	1521.02	1529.69
0.888	998.295	997.157	995.760	994.142	992.314	0.888	1483.80	1497.61	1509.78	1520.39	1529.44
1.110	998.313	997.154	995.757	994.139	992.316	1.110	1483.59	1497.57	1509.85	1520.51	1529.56
1.332	998.307	997.146	995.727	994.058	992.239	1.332	1483.63	1497.42	1509.67	1520.32	1529.39
1.554	998.297	997.150	995.750	994.127	992.305	1.554	1483.54	1497.38	1509.63	1520.25	1529.36
1.776	998.294	997.146	995.745	994.126	992.307	1.776	1483.55	1497.52	1509.69	1520.29	1529.37
1.998	998.284	997.138	995.740	994.121	992.303	1.998	1482.73	1496.84	1509.25	1520.01	1529.12
2.220	998.281	997.132	995.737	994.117	992.300	2.220	1482.56	1496.70	1509.18	1519.64	1529.07
0.1% w/w PVP											
0.000	998.434	997.309	995.949	994.329	992.464	0.000	1483.28	1497.31	1509.60	1520.34	1529.50
0.222	997.995	997.348	995.958	994.340	992.520	0.222	1483.61	1497.62	1509.92	1520.71	1529.90
0.444	998.512	997.357	995.980	994.339	992.510	0.444	1483.62	1497.55	1509.80	1520.47	1529.55
0.666	998.506	997.353	995.952	994.336	992.510	0.666	1483.60	1497.54	1509.77	1520.44	1529.53
0.888	998.504	997.359	995.958	994.338	992.521	0.888	1483.70	1497.64	1509.87	1520.52	1529.64
1.110	998.515	997.359	995.956	994.336	992.515	1.110	1483.92	1497.88	1510.05	1520.61	1529.68
1.332	998.493	997.347	995.946	994.323	992.502	1.332	1483.86	1497.80	1509.97	1520.61	1529.67
1.554	998.486	997.342	995.941	994.321	992.496	1.554	1483.83	1497.74	1509.95	1520.59	1529.67
1.776	998.490	997.337	995.937	994.317	992.490	1.776	1483.78	1497.71	1509.92	1520.57	1529.64
1.998	998.485	997.332	995.931	994.311	992.487	1.998	1483.85	1497.77	1509.99	1520.60	1529.67
2.220	998.480	997.328	995.926	994.305	992.484	2.220	1483.93	1497.84	1510.05	1520.65	1529.70
0.3% w/w PVP											
0.000	998.878	997.717	996.305	994.696	992.871	0.000	1483.71	1497.77	1510.24	1521.00	1530.14
0.222	998.480	997.727	996.328	994.708	992.883	0.222	1484.14	1498.08	1510.29	1520.93	1530.00
0.444	998.883	997.722	996.319	994.698	992.875	0.444	1484.35	1498.27	1510.49	1521.13	1530.21
0.666	998.888	997.732	996.331	994.703	992.880	0.666	1484.44	1498.35	1510.55	1521.19	1530.26
0.888	998.882	997.727	996.323	994.699	992.835	0.888	1484.43	1498.33	1510.53	1521.14	1530.19
1.110	998.881	997.722	996.318	994.695	992.866	1.110	1484.47	1498.37	1510.56	1521.18	1530.23
1.332	998.864	997.711	996.307	994.684	992.859	1.332	1484.57	1498.42	1510.61	1521.22	1530.24
1.554	998.857	997.706	996.302	994.679	992.852	1.554	1484.56	1498.43	1510.61	1521.22	1530.26
1.776	998.819	997.704	996.302	994.679	992.957	1.776	1484.64	1498.48	1510.67	1521.26	1530.29
1.998	998.865	997.705	996.298	994.674	992.846	1.998	1484.60	1498.48	1510.64	1521.24	1530.27
2.220	998.857	997.698	996.290	994.665	992.840	2.220	1484.65	1498.53	1510.71	1521.31	1530.33

Standard uncertainties (u) are u(T) = ± 0.01 K, u([TBADS]) = ± 0.002 mmol kg^{-1}, u(ρ) = ± 0.08 kg m^{-3}, u(u) = ± 0.1 m s^{-1}.

and 0.3% w/w) within 293.15 K- 313.15 K. After careful analysis of the density data, it appears that the ρ values decrease as the temperature increases in all PVP systems. This could be because the volume expands as a result of incremental kinetic energy, that could have adverse effects on the structured water [12,37,38]. In contrast, there has been evidence of an increase in the u values with temperature and polymer concentrations, which could be attributed to volume restriction resulting from the molecular association of SAIL, polymer and water [12].

The values of ρ and u were further employed to enumerate the volumetric, compressibility and acoustic parameters, which provided valuable insight on interactions prevailing in SAIL-polymer-water system. The isentropic compressibility (κ_s) values can be calculated by using eqn. 1 [39-41].

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

Based on Fig.1, the κ_s values decrease linearly with increases [PVP] and temperature, which suggests there may be interactions between the solute and solvent. Furthermore, the increase in [PVP] leads to a decrease in the κ_s values, which could be attributed to two factors *viz*. (i) the interactions between ions and solvents, which helps the compactness of the ternary system (SAIL-PVP-water) and (ii) the enhanced electrostrictive compression resulting from the interactions between the non-polar part of polymers and SAILs [36,39,40].

Tables 2 and 3 illustrated the apparent molar volume (V_ϕ) and compressibility ($\kappa_{s,\phi}$) values, which can be evaluated by using relations 2 and 3 [12,36,38,39,41,42] and inferred the diverse interaction in the solute-solvent system. The data based in Table-2 indicated that TBADS has positive V_ϕ values in all the studied [PVP].

$$V_\phi = \frac{M}{\rho} - \left(\frac{(\rho-\rho_0)}{m\rho\rho_0}\right) \quad (2)$$

$$\kappa_{s,\phi} = \left(\frac{\kappa_s - \kappa_{s,0}}{m\rho_0}\right) + \kappa_s V_\phi \quad (3)$$

where m is the molality of solution in mol kg^{-1}; M is the molar mass of TBADS, ρ and ρ_0 are the densities of solution and pure solvent, respectively.

The variations in V_ϕ values depend upon interactions in the SAIL-Polymer-water system *via* (i) hydrophobic interactions between the alkyl chain of SAIL and polymer resulting in the breakage of structured water, hence V_ϕ values decreased and (ii) the interactions between the ionic and polar components of SAILs and polymers lead to a decrease in volume due to the formation of a structured network, which enhances the solvent structure with increased values of volume fraction (V_ϕ) [12,36] (Table-2). Similarly, the values of V_ϕ have also been found to increase with enhanced [polymer] for TBADS because of the incremental interactions between ionic/polar parts of SAILs/polymers in the SAIL-polymer complex [12,40].

The values of $\kappa_{s,\phi}$ at all temperatures, [SAIL] and [polymer] are presented in Table-3 and shown the non-linear variation in all cases. Fig. 2 illustrates the variation of $\kappa_{s,\phi}$ with [TBADS] in aqueous solution of PVP at different temperatures (293.15-313.15 K). The $\kappa_{s,\phi}$ values were found to be less negative (or more positive) with increasing [SAIL] in all cases, which may be attributable to the liberation of several water molecules from the counter-ion during the binding to micelles, resulting into the facilitated micelle formation with improved compressibility [12]. Similar behaviour was also observed with the increased temperature due to the dissipation of hydrophobic hydration, indicating the significance of solute-solvent interactions in SAIL-polymer system [38,39], whereas hydrophilic hydration may be the cause of strong SAIL-polymer interactions resulting in $\kappa_{s,\phi} < 0$ [12].

Acoustical parameters: The measured ρ and u values were also utilized to calculate important acoustical parameters by using the relations 4-7, such as intermolecular free length (L_f), relative association (RA), specific acoustic impedance (Z) and molar sound number [U]. These parameters were preferred as they provide the supportive insights into SAILs/polymer interactions in aqueous medium [40,43-45].

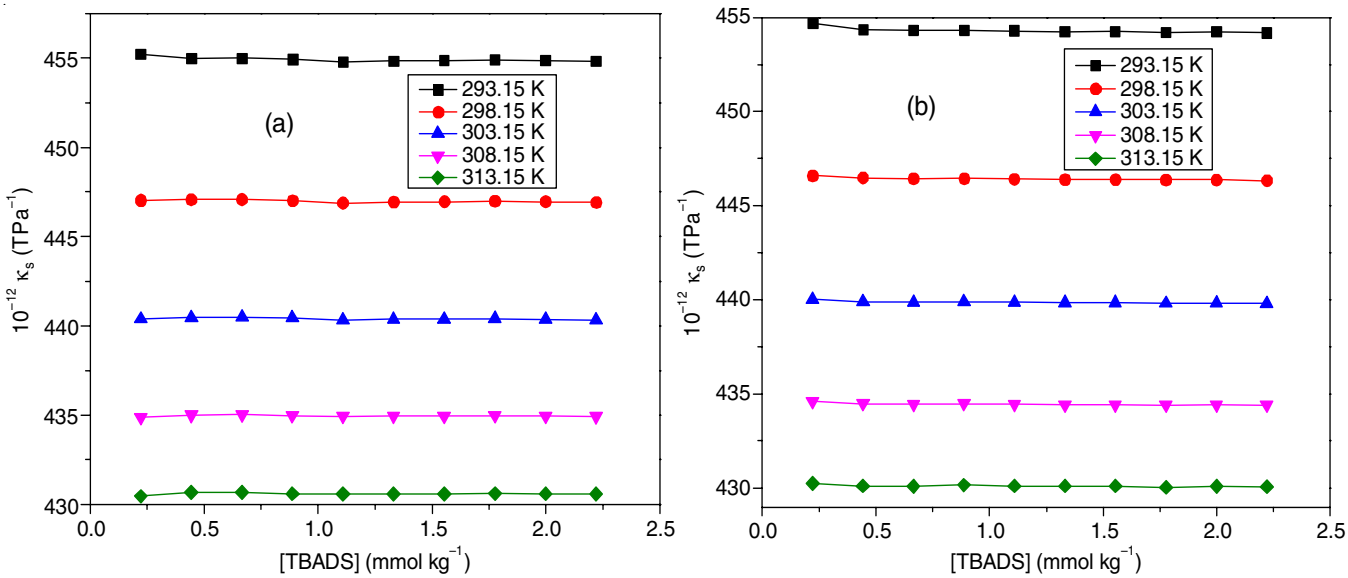

Fig. 1. Plots of κ_s *vs*. [TBADS] in (a) 0.1% w/w and (b) 0.3% w/w aqueous solution of PVP

TABLE-2
VALUES OF APPARENT MOLAR VOLUME (10^{-4} V_ϕ) (m^3 mol^{-1}) FOR TBADS IN AQUEOUS PVP SOLUTIONS AT DIFFERENT TEMPERATURES (293.15-313.15 K)

[TBADS] (mmol kg^{-1})	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
0.0% w/w PVP					
0.222	26.890	66.627	106.716	155.334	232.216
0.444	3.708	2.487	2.396	2.441	2.487
0.666	4.017	3.431	3.464	4.090	5.362
0.888	4.160	3.824	3.805	3.763	3.848
1.110	4.183	4.105	4.091	4.060	4.084
1.332	4.379	4.330	4.487	4.850	4.843
1.554	4.544	4.413	4.425	4.437	4.451
1.776	4.629	4.521	4.538	4.527	4.523
1.998	4.730	4.625	4.625	4.617	4.609
2.220	4.780	4.699	4.686	4.684	4.674
0.1% w/w PVP					
0.222	24.934	3.326	4.690	4.606	2.556
0.444	3.324	4.005	4.395	4.879	4.065
0.666	4.002	4.428	5.054	5.001	4.415
0.888	4.295	4.526	4.997	5.005	4.465
1.110	4.354	4.639	5.035	5.043	4.650
1.332	4.642	4.805	5.122	5.153	4.827
1.554	4.750	4.878	5.151	5.159	4.908
1.776	4.770	4.933	5.167	5.176	4.968
1.998	4.830	4.976	5.190	5.198	5.000
2.220	4.878	5.006	5.204	5.217	5.025
0.3% w/w PVP					
0.222	23.062	4.637	4.053	4.559	4.566
0.444	4.971	4.977	4.779	5.060	5.023
0.666	4.934	4.864	4.704	4.999	4.978
0.888	5.039	4.977	4.893	5.071	5.526
1.110	5.057	5.045	4.979	5.115	5.161
1.332	5.189	5.135	5.082	5.197	5.206
1.554	5.219	5.161	5.116	5.216	5.239
1.776	5.417	5.164	5.114	5.202	4.623
1.998	5.149	5.150	5.133	5.217	5.242
2.220	5.179	5.176	5.165	5.247	5.257

Standard uncertainties (u) are u(T) = ± 0.01 K, u([TBADS]) = ± 0.002 mmol kg^{-1}, u (10^{-4} V_ϕ) = ± 0.06 m^3 mol^{-1}

TABLE-3
APPARENT MOLAR COMPRESSIBILITY (10^{-12} $\kappa_{s,\phi}$) VALUES (m^3 mol^{-1} TPa^{-1}) FOR TBADS IN AQUEOUS PVP SOLUTIONS AT DIFFERENT TEMPERATURES (293.15-313.15 K)

[TBADS] (mmol kg^{-1})	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
0.0% w/w PVP					
0.222	-0.971	3.223	6.783	10.484	16.651
0.444	-1.916	-2.002	-2.073	-2.357	-2.422
0.666	-1.426	-1.324	-1.161	-1.008	-0.492
0.888	-0.677	-0.500	-0.358	-0.343	-0.279
1.110	-0.394	-0.331	-0.276	-0.289	-0.242
1.332	-0.304	-0.165	-0.094	-0.068	-0.042
1.554	-0.186	-0.095	-0.046	-0.040	-0.031
1.776	-0.136	-0.100	-0.030	-0.020	-0.004
1.998	0.162	0.144	0.130	0.090	0.094
2.220	0.218	0.193	0.159	0.201	0.121
0.1% w/w PVP					
0.222	1.125	-0.766	-0.656	-0.781	-1.022
0.444	-0.400	-0.193	-0.101	0.034	0.066
0.666	-0.163	-0.039	0.071	0.127	0.134
0.888	-0.131	-0.046	0.037	0.097	0.075
1.110	-0.190	-0.120	-0.019	0.077	0.088
1.332	-0.077	-0.018	0.064	0.109	0.123
1.554	-0.017	0.043	0.097	0.134	0.140
1.776	0.030	0.079	0.125	0.154	0.163
1.998	0.033	0.079	0.118	0.155	0.162
2.220	0.033	0.077	0.115	0.151	0.161
0.3% w/w PVP					
0.222	0.677	-0.648	0.001	0.356	0.530
0.444	-0.663	-0.456	-0.133	0.050	0.123
0.666	-0.455	-0.313	-0.083	0.049	0.106
0.888	-0.270	-0.160	0.015	0.128	0.224
1.110	-0.191	-0.100	0.045	0.129	0.178
1.332	-0.155	-0.060	0.060	0.135	0.185
1.554	-0.092	-0.020	0.087	0.150	0.187
1.776	-0.060	-0.005	0.084	0.146	0.130
1.998	-0.036	0.020	0.110	0.162	0.194
2.220	-0.020	0.030	0.106	0.154	0.184

Standard uncertainties (u) are u(T) = ± 0.01 K, u([TBADS]) = ± 0.002 mmol kg^{-1}, u(10^{-12} $\kappa_{s,\phi}$) = ± 0.03 m^3 mol^{-1} TPa^{-1}

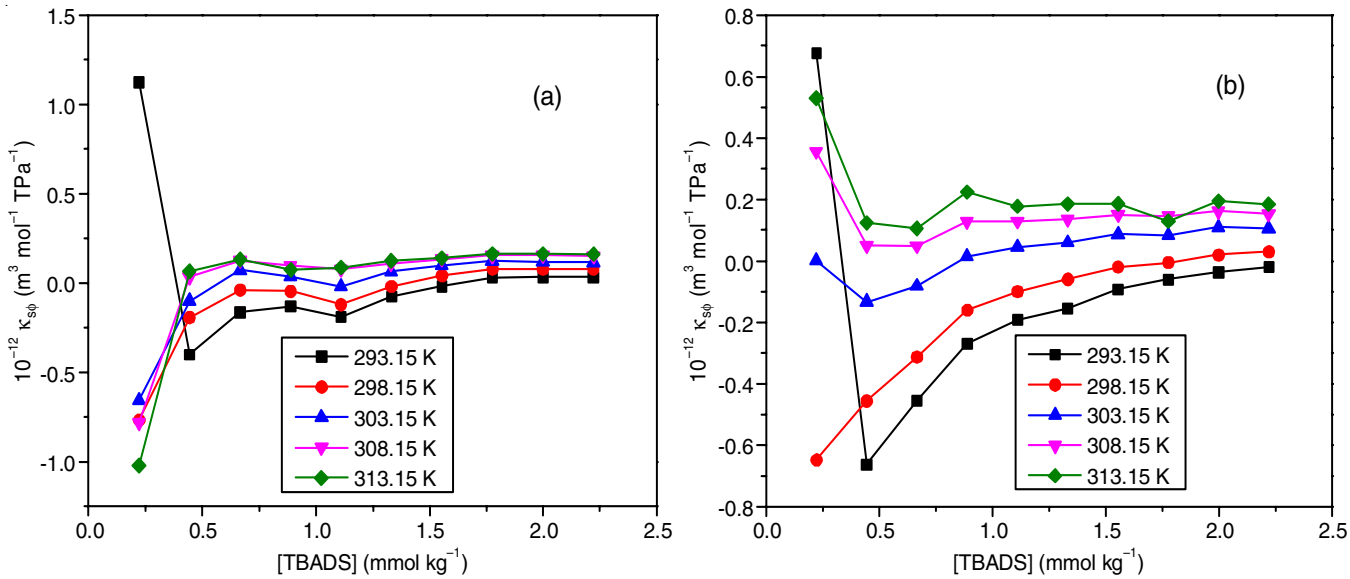

Fig. 2. Plots of $\kappa_{s,\phi}$ *vs.* [TBADS] in (a) 0.1% w/w and (b) 0.3% w/w aqueous solution of PVP

$$L_f = K\sqrt{\kappa_s} \quad (4)$$

$$RA = \left(\frac{\rho}{\rho_0}\right)\left(\frac{u_0}{u}\right)^{1/3} \quad (5)$$

$$Z = u \times \rho \quad (6)$$

$$[U] = \frac{(u - u_0)}{(u_0 \times m)} \quad (7)$$

where $K = [(93.875 + 0.375\ T) \times 10^{-8}]$.

Table-4 exhibited a decreasing and increasing irregular pattern in L_f values when the [PVP] and temperature increased, respectively. The decrease in L_f values may be attributed to the strong intermolecular interactions between SAIL and polymer molecules, leading to a structural readjustment in the mixture and the formation of a tightly packed system. In addition, the higher temperature might lead to a rise in thermal energy, allowing the molecules to spread out more and resulting in a volume expansion and an increase in free length [43,44]. The relative association (RA) values may increase or decrease with temperature, [polymer] and [SAIL] (Table-5) due to (i) the breakage of solvent structure in the occurrence of solute and (ii) successive solvation of ions by the liberated solvent molecules. Hence, increased RA values may be due to the outcome of (ii), whereas decreased value may be due to (i) [43,44]. Also, the RA values are found to be positive and close to unity.

The relationship between temperature and the increasing trend of specific acoustic impedance (Z) values with [polymer] is shown in Fig. 3, which indicate the strong interactions among constituents of the SAIL-polymer-water mixture and provides a greater obstruction to the sound waves [43,44]. Another significant parameter, molar sound number ([U]) provides the distinct information about intermolecular interactions and changes in the structure of a solution (Table-6), while the molar sound number exhibits non-linear behaviour (Fig. 4) highlight the strong interaction between SAILs and polymers, which cause micellization in the final phase [43,44].

TABLE-4
MEAN FREE LENGTH (10^{-11} L_f) VALUES (m) FOR TBADS IN AQUEOUS PVP SOLUTIONS AT DIFFERENT TEMPERATURES (293.15-313.15 K)

[TBADS] (mmol kg^{-1})	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
0.0% w/w PVP					
0.222	4.345	4.349	4.358	4.372	4.392
0.444	4.343	4.344	4.351	4.363	4.379
0.666	4.343	4.344	4.351	4.364	4.382
0.888	4.344	4.346	4.354	4.366	4.383
1.110	4.345	4.346	4.353	4.365	4.382
1.332	4.345	4.347	4.354	4.366	4.383
1.554	4.345	4.347	4.354	4.366	4.383
1.776	4.345	4.346	4.354	4.366	4.383
1.998	4.347	4.348	4.355	4.367	4.384
2.220	4.348	4.349	4.355	4.368	4.384
0.1% w/w PVP					
0.222	4.345	4.346	4.353	4.364	4.381
0.444	4.344	4.346	4.353	4.365	4.382
0.666	4.344	4.346	4.353	4.365	4.382
0.888	4.344	4.346	4.353	4.365	4.382
1.110	4.343	4.345	4.352	4.365	4.382
1.332	4.344	4.345	4.353	4.365	4.382
1.554	4.344	4.345	4.353	4.365	4.382
1.776	4.344	4.345	4.353	4.365	4.382
1.998	4.344	4.345	4.353	4.365	4.382
2.220	4.343	4.345	4.352	4.365	4.382
0.3% w/w PVP					
0.222	4.343	4.344	4.351	4.363	4.380
0.444	4.341	4.343	4.350	4.362	4.379
0.666	4.341	4.343	4.350	4.362	4.379
0.888	4.341	4.343	4.350	4.362	4.380
1.110	4.341	4.343	4.350	4.362	4.379
1.332	4.341	4.343	4.350	4.362	4.379
1.554	4.341	4.343	4.350	4.362	4.379
1.776	4.341	4.342	4.350	4.362	4.379
1.998	4.341	4.342	4.350	4.362	4.379
2.220	4.340	4.342	4.350	4.362	4.379

Standard uncertainties (u) are u(T) = ± 0.01 K, u([TBADS]) = ± 0.002 mmol kg^{-1}, u(10^{-11} L_f) = ± 0.008 m

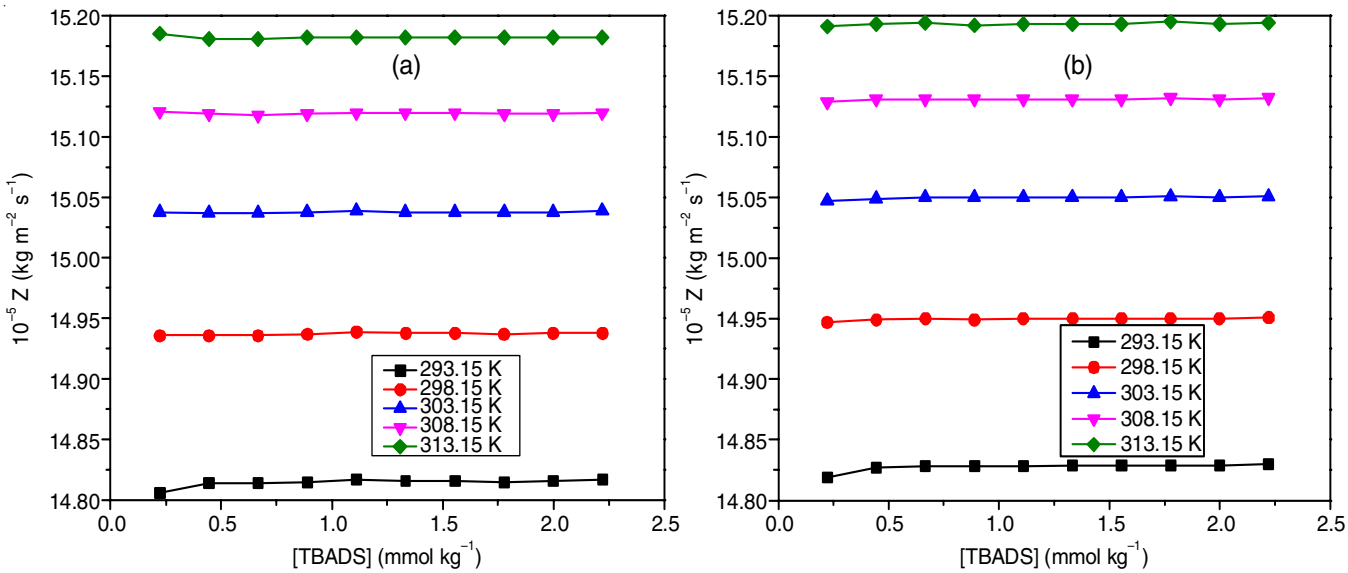

Fig. 3. Plots of Z *vs*. [TBADS] in (a) 0.1% w/w and (b) 0.3% w/w aqueous solution of PVP

TABLE-5
RELATIVE ASSOCIATION (RA) VALUES
FOR TBADS IN AQUEOUS PVP SOLUTIONS AT
DIFFERENT TEMPERATURES (293.15-313.15 K)

[TBADS] (mmol kg^{-1})	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
0.0% w/w PVP					
0.222	0.99926	0.99843	0.99756	0.99646	0.99475
0.444	0.99973	0.99979	0.99978	0.99972	0.99970
0.666	0.99969	0.99976	0.99980	0.99978	0.99980
0.888	0.99981	0.99991	0.99996	0.99997	0.99998
1.110	0.99988	0.99992	0.99994	0.99994	0.99995
1.332	0.99987	0.99994	0.99995	0.99990	0.99991
1.554	0.99986	0.99995	0.99998	0.99998	0.99999
1.776	0.99985	0.99992	0.99996	0.99997	0.99999
1.998	0.99986	1.00006	1.00005	1.00003	1.00004
2.220	0.99986	1.00009	1.00007	1.00011	1.00005
0.1% w/w PVP					
0.222	0.99949	0.99997	0.99994	0.99993	0.99997
0.444	1.00000	0.99999	0.99999	0.99998	1.00004
0.666	1.00000	0.99999	0.99997	0.99999	1.00004
0.888	0.99998	0.99998	0.99995	0.99997	1.00003
1.110	0.99994	0.99992	0.99991	0.99995	1.00001
1.332	0.99992	0.99993	0.99992	0.99993	1.00000
1.554	0.99991	0.99994	0.99991	0.99994	1.00000
1.776	0.99993	0.99994	0.99992	0.99994	1.00000
1.998	0.99993	0.99992	0.99990	0.99992	0.99999
2.220	0.99993	0.99990	0.99988	0.99991	0.99998
0.3% w/w PVP					
0.222	0.99951	0.99994	1.00001	1.00003	1.00004
0.444	0.99986	0.99989	0.99996	0.99997	0.99999
0.666	0.99985	0.99989	0.99996	0.99997	0.99998
0.888	0.99984	0.99989	0.99995	0.99997	0.99995
1.110	0.99983	0.99987	0.99994	0.99996	0.99998
1.332	0.99982	0.99985	0.99992	0.99994	0.99997
1.554	0.99981	0.99984	0.99992	0.99993	0.99995
1.776	0.99975	0.99983	0.99990	0.99993	1.00005
1.998	0.99980	0.99983	0.99990	0.99993	0.99995
2.220	0.99977	0.99981	0.99988	0.99990	0.99993

Standard uncertainties (u) are u(T) = ± 0.01 K, u([TBADS]) = ± 0.002 mmol kg^{-1}, u(RA) = ± 3 × 10^{-5}

TABLE-6
MOLAR SOUND NUMBER ([U]) VALUES
FOR TBADS IN AQUEOUS PVP SOLUTIONS AT
DIFFERENT TEMPERATURES (293.15-313.15 K)

[TBADS] (mmol kg^{-1})	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
0.0% w/w PVP					
0.222	3.494	2.799	2.716	3.231	3.654
0.444	2.218	2.227	2.328	2.682	2.784
0.666	1.712	1.565	1.403	1.304	0.845
0.888	0.904	0.685	0.530	0.511	0.449
1.110	0.595	0.524	0.466	0.480	0.430
1.332	0.516	0.361	0.298	0.306	0.275
1.554	0.404	0.292	0.239	0.233	0.223
1.776	0.357	0.308	0.231	0.219	0.199
1.998	0.041	0.047	0.060	0.102	0.095
2.220	-0.015	0.000	0.033	-0.018	0.071
0.1% w/w PVP					
0.222	1.002	0.933	0.955	1.096	1.178
0.444	0.516	0.361	0.298	0.193	0.074
0.666	0.324	0.231	0.169	0.099	0.029
0.888	0.319	0.248	0.201	0.133	0.103
1.110	0.389	0.343	0.269	0.160	0.106
1.332	0.294	0.246	0.184	0.133	0.083
1.554	0.239	0.185	0.149	0.106	0.072
1.776	0.190	0.150	0.119	0.085	0.052
1.998	0.192	0.154	0.129	0.086	0.056
2.220	0.197	0.159	0.134	0.092	0.059
0.3% w/w PVP					
0.222	1.305	0.932	0.149	-0.207	-0.412
0.444	0.972	0.752	0.373	0.193	0.103
0.666	0.739	0.581	0.308	0.188	0.118
0.888	0.546	0.421	0.216	0.104	0.037
1.110	0.461	0.361	0.191	0.107	0.053
1.332	0.435	0.326	0.184	0.109	0.049
1.554	0.369	0.284	0.158	0.093	0.050
1.776	0.353	0.267	0.160	0.096	0.055
1.998	0.300	0.237	0.133	0.079	0.043
2.220	0.285	0.229	0.140	0.092	0.056

Standard uncertainties (u) are u(T) = ± 0.01 K, u([TBADS]) = ± 0.002 mmol kg^{-1}, u([U]) = ± 0.009

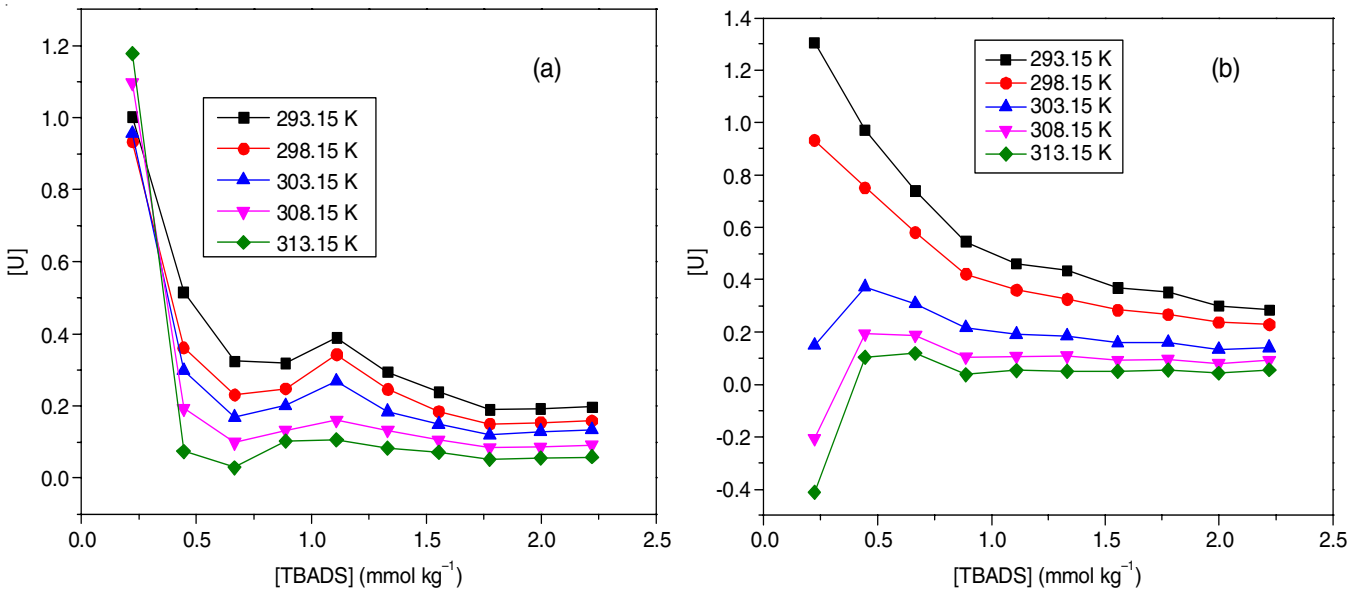

Fig. 4. Plots of [U] *vs.* [TBADS] in (a) 0.1% w/w and (b) 0.3% w/w aqueous solution of PVP

Conclusion

The introduction of biocompatible polymer (PVP) has considerable influence on the volumetric, compressibility and acoustical parameters of eco-friendly surface active ionic liquids (SAIL) tetrabutylammonium dodecylsulphate (TBADS). The feasible factors accountable for these variations have been attributed to hydrophobic/hydrophilic interactions causing the liberation of organized water about the apolar tails. The observed compactness of the investigated SAIL-polymer-water system, along with the deviating behaviour in the pre- and post-micellar regions, provides evidence of the presence of interactions. The study of diverse molecular interactions in such biocompatible systems can be utilized to recreate a sensible function for the evolution of technological and pharmaceutical fields where SAILs are the important components.

ACKNOWLEDGEMENTS

One of the authors, Manish, thanks UGC, New Delhi for the award of Senior Research Fellowship.

CONFLICT OF INTEREST

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

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