

# SOLUTE-SOLVENT AND SOLUTE-SOLUTE INTERACTIONS OF TETRABUTYLAMMONIUM BROMIDE IN DMF-WATER SYSTEMS AT DIFFERENT TEMPERATURES

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## ABSTRACT

Ultrasonic velocities in solution of tetrabutylammonium bromide (TBAB) in 10, 20 and 30 %w/w N,N-dimethylformamide (DMF)-water mixtures were measured at 303 K, 308 K and 313 K by using the pulse echo overlap method at a frequency of 3 MHz. The ultrasonic velocity, density, and viscosity were used to calculate the adiabatic compressibility, apparent molal compressibility, apparent molal volume, limiting apparent molal compressibility, limiting apparent molal volume, free volume, internal pressure, solvation number, and viscosity B-coefficient. The observed variation in these parameters with respect to the molality highlights ion-solvent and ion-ion interactions were present, ion-solvent interactions were much pronounced in lower DMF content as well as at lower molalities and ion-ion interactions were very apparent in higher DMF content and at higher salt molality.

**KEYWORDS:** Adiabatic compressibility; apparent molal compressibility; apparent molal volume; free volume; viscosity B-coefficient.

## I. INTRODUCTION

A literature survey shows that studies on the ultrasonic velocity and related parameters in mixed solvents containing electrolytes has been extensively carried out by many workers [1-5]. Studies of densities, viscosities, and ultrasonic speeds of electrolytic solutions are of great use in characterizing the structure and properties of solutions. Various types of interactions exist between the solutes in solutions, and these solute-solute and solute-solvent interactions are of current interest in all branches of chemistry. These interactions provide a better understanding of the nature of the solute and solvent i.e., whether the solute modifies or distorts the structure of the solvent. Recently, ion-ion and ion-solvent interactions for the tetraalkylammonium salts have been reported [6,7] from density and viscosity measurements. The present work is an attempt to study the molecular interactions between the components of a mixed salt solution in terms of the parameters.

## II. EXPERIMENTAL

Commercially available AR grade chemicals N,N-dimethylformamide (DMF), tetrabutylammonium bromide (TBAB), and double-distilled water were used for preparing the electrolytes. The ultrasonic velocity of the electrolytic mixtures was measured using the pulse echo overlapping method at a fixed frequency of 3 MHz with an uncertainty of 0.1 %. A more detailed description of the equipment may be found elsewhere [8]. The measuring cell temperature was maintained by using an electronically controlled thermostat having an uncertainty of 0.01 K. The density of the mixtures was measured using a specific gravity bottle with an uncertainty of 0.1 kg.m<sup>-3</sup>. The viscosity measurements have

been carried out using an Ostwald viscometer. The overall uncertainty of the measurement of viscosity is 0.001 N.s.m<sup>-2</sup>.

### III. THEORY

The adiabatic compressibility ( $\beta$ ) of the systems have been calculated using the relation [9],

$$\beta = 1 / \rho U^2 \quad (1)$$

where  $U$  and  $\rho$  are the sound speeds and densities of the electrolyte solutions.

The apparent molal compressibility ( $\phi_k$ ) of the systems have been calculated using the relation,

$$\phi_k = (1000 / m \rho^0) (\rho^0 \beta - \beta^0 \rho) + (\beta^0 M / \rho^0) \quad (2)$$

where  $\beta$ ,  $\rho$  and  $\beta^0$ ,  $\rho^0$  are the adiabatic compressibility and density of the solution and solvent, respectively.  $M$  is the molar mass of the solute, and  $m$  is the molal concentration.  $\phi_k$  is a function of  $m$  obtained by Gucker [10] from Debye Hückel theory [11] and is given by

$$\phi_k = \phi_k^o + S_k m^{1/2} \quad (3)$$

where  $\phi_k^o$  is the limiting apparent molal compressibility at infinite dilution and  $S_k$  is a constant.

The apparent molal volume ( $\phi_v$ ) of a solute has been obtained as

$$\phi_v = (1000 / m \rho^0) (\rho^0 - \rho) + (M / \rho^0) \quad (4)$$

The apparent molal volume has been found to vary with concentration in agreement with Masson's empirical relation [12] as

$$\phi_v = \phi_v^o + S_v m^{1/2} \quad (5)$$

where  $\phi_v^o$  is the limiting apparent molal volume at infinite dilution and  $S_v$  is a constant.

Suryanarayana [13, 14], and Suryanarayana and Kuppasamy [15] relations have been employed to compute the free volume ( $V_f$ ) and internal pressure ( $\pi_i$ );

$$V_f = (M_{eff} U / K \eta)^{3/2} \quad (6)$$

$$\text{and } \pi_i = bRT (K \eta / U)^{1/2} (\rho^{2/3} / M_{eff}^{7/6}) \quad (7)$$

where  $M_{eff} = M_1 X_1 + M_2 X_2$ , called the effective molar mass,  $U$  is the ultrasonic speed,  $K$  is a constant ( $4.28 \times 10^9$ ),  $\eta$  is the viscosity,  $\rho$  is the density,  $b$  is the packing factor,  $R$  is the universal gas constant, and  $T$  is the temperature.

The solvation number has been calculated using the following relation:

$$S_n = (M / M_o) (1 - \beta / \beta_o) (100 - x / x) \quad (8)$$

where  $M_o$  and  $M$  are the molar mass of the solvent and solution, respectively,  $\beta_o$  and  $\beta$  are the adiabatic compressibility of the solvent and solution, respectively, and  $x$  is the number of grams of salt in 100 g of the solution.

### IV. RESULTS AND DISCUSSION

The experimental values of density, viscosity, and sound speed as a function of the concentration of TBAB salt in different DMF aqueous solution at 303 K, 308 K and 313 K have been reported in Table 1. The calculated values of the adiabatic compressibility, apparent molal compressibility, and apparent molal volume are reported in Table 2. The values of the limiting apparent molal compressibility, limiting apparent molal volume, and the constants  $S_k$  and  $S_v$  for TBAB salt are presented in Table 3. The calculated values of the free volume, internal pressure, and the arbitrary constants  $a$ ,  $b$ ,  $c$ , and  $d$  for the ternary systems at different molalities and temperatures are given in Table 4. The values of the viscosity  $B$ -coefficient are given in Table 5, and the solvation number is reported in Table 6.

#### 4.1. Ultrasonic Speed and Adiabatic Compressibility

From Table 1, ultrasonic speeds in the electrolytic solution (TBAB) were found to vary linearly with increasing molalities of the solutions as well as with increasing the concentration of DMF in solvent composition. The molality of electrolytic solution increases due to formation of free ions in the solution which leads to increase in ultrasonic speeds.

Moreover, the ultrasonic speeds are increases due to decrease in water solvation effect on electrolyte with increase in DMF concentration. This might be due to the electrostatic effect of a solvent on an electrolyte [16].

The variation of the sound speed of electrolytic solutions with molality in water can also be expressed in terms of derivatives of density ( $\rho$ ) and adiabatic compressibility ( $\beta$ ):

$$\frac{dU}{dm} = -\frac{U}{2} \left[ \frac{1}{\rho} \frac{d\rho}{dm} + \frac{1}{\beta} \frac{d\beta}{dm} \right] \quad (9)$$

The above equation shows that the molality dependence of the ultrasonic velocity is determined by the behavior of the density ( $\rho$ ) and adiabatic compressibility ( $\beta$ ) as the concentration is varied. The quantity ( $d\rho/dm$ ) is positive, while ( $d\beta/dm$ ) is negative in the present case. Since the values of ( $1/\beta$ )  $d\beta/dm$  are larger than those of ( $1/\rho$ )  $d\rho/dm$  for the salt, the molality derivative of the sound velocity ( $dU/dm$ ) is positive which agrees with previous results [17, 18] for potassium thiocyanate, sodium perchlorate, magnesium chloride, and beryllium perchlorate in DMF electrolytic solutions.

**Table-1** Density ( $\rho$ ), viscosity ( $\eta$ ) and sound speed ( $U$ ) of TBAB in DMF–water mixtures.

Molality of salt (m)	$\rho$ (kg.m <sup>-3</sup> )			$\eta \times 10^3$ ( N.s.m <sup>-2</sup> )			$U$ ( m.s <sup>-1</sup> )		
	Temperature (K)			Temperature (K)			Temperature (K)		
	303	308	313	303	308	313	303	308	313
	DMF - Water (10:90 %w/w)								
0.1999	990.3	985.2	980.1	1.343	1.316	1.245	1587.9	1589.4	1598.1
0.4000	992.5	988.4	983.3	1.388	1.356	1.303	1596.6	1597.6	1602.7
0.5999	993.6	991.6	987.5	1.474	1.428	1.377	1606.7	1607.3	1609.5
0.8000	995.4	993.8	990.7	1.523	1.463	1.412	1620.2	1626.8	1630.8
1.0002	999.7	996.1	994.9	1.601	1.535	1.516	1627.2	1630.2	1637.6
	DMF - Water (20:80 %w/w)								
0.2002	986.3	982.4	978.6	1.401	1.381	1.312	1615.4	1621.4	1627.6
0.3999	989.6	985.8	981.1	1.452	1.409	1.360	1620.4	1629.2	1635.2
0.6001	992.9	988.2	985.2	1.523	1.483	1.389	1636.0	1638.8	1641.3
0.7999	994.2	991.6	988.1	1.549	1.520	1.486	1642.2	1643.7	1644.5
1.0001	997.5	995.0	993.3	1.652	1.589	1.576	1648.4	1652.4	1656.2
	DMF - Water (30:70 %w/w)								
0.2001	984.7	979.8	976.9	1.465	1.390	1.358	1633.3	1643.6	1649.3
0.3999	985.5	983.2	979.8	1.525	1.477	1.399	1643.9	1651.6	1653.3
0.6001	987.2	985.4	984.6	1.659	1.599	1.472	1648.9	1657.5	1662.0
0.7998	991.4	988.3	984.7	1.682	1.613	1.512	1655.5	1662.3	1669.5
1.0002	995.3	992.7	990.5	1.734	1.697	1.583	1665.8	1670.3	1673.8

In these salt solutions, the ions of opposite charges are dissociated due to interactions between the ions and solvent, and there will be a cloud of ions of positive and negative charges around a solvated finite charge ion in solution [12]. The Br<sup>-</sup> ions associate themselves with water molecules and also with a complex of DMF-water mixture [19], resulting in an increase in the ultrasonic velocity and hence a decrease in the compressibility. Therefore, solvent molecules around the solute ions increase as a consequence of ion-solvent interactions, suggesting an increase of intermolecular forces [20, 21] and may affect the structural arrangement.

The adiabatic compressibility ( $\beta$ ) decreases and the density ( $\rho$ ) increases with increasing concentration of the solutions. It is related to the ultrasonic velocity, ( $U$ ) and density, ( $\rho$ ) data of electrolytic solutions. Since  $\beta$  and  $U$  are known to be inversely proportional to each other, these variations have been found to be linearly convergent in the case of electrolytic solutions which show weak interactions. This decrease in the adiabatic compressibility is expected due to the structure-making effect of TBAB [22].

## 4.2. Apparent Molal Compressibility

From Table 2,  $\phi_k$  values are negative for the electrolytic solutions over the entire range of molality and temperature. The  $\phi_k$  values decrease with an increase in DMF content and with an increase in temperature. For the electrolytic solutions, the maximum negative value of  $\phi_k$  occurs at a concentration of 10 %w/w of DMF. All the above observations clearly suggest that the  $\phi_k$  values for the electrolytic solution are comparatively higher than that of the solvent, thereby indicating a strong ion-solvent interaction.

Since a larger number of water molecules are available at a lower DMF concentration (10 %w/w) the chances for dissolution of the solute in the solvent are highly favored. This is indicated by the maximum  $\phi_k$  values at 10 %w/w DMF concentration for the systems.

**Table-2** Adiabatic compressibility ( $\beta$ ), apparent molal compressibility ( $\phi_k$ ), and apparent molal volume ( $\phi_v$ ) of TBAB in DMF – water mixtures.

Molality of salt (m)	$\beta \times 10^{10}$ (Pa <sup>-1</sup> )			$-\phi_k \times 10^{10}$ (m <sup>2</sup> .N <sup>-1</sup> )			$-\phi_v$ (m <sup>3</sup> .mol <sup>-1</sup> )		
	Temperature (K)			Temperature (K)			Temperature (K)		
	303	308	313	303	308	313	303	308	313
DMF - Water (10:90 %w/w)									
0.1999	4.0180	4.0049	3.9950	851.60	834.60	856.10	44.98	50.26	61.48
0.4000	3.9640	3.9592	3.9525	730.05	736.21	701.77	38.10	33.32	38.99
0.5999	3.9091	3.9036	3.8987	684.31	677.66	681.63	27.28	27.68	33.22
0.8000	3.8271	3.8022	3.7954	537.28	549.16	595.52	22.76	23.58	29.04
1.0002	3.7779	3.7776	3.7480	497.31	473.65	481.82	21.60	21.21	27.57
DMF - Water (20:80 %w/w)									
0.2002	3.8854	3.8720	3.8574	626.50	623.26	750.59	50.81	55.81	68.82
0.3999	3.8485	3.8218	3.8119	539.47	464.00	515.14	36.40	32.14	40.93
0.6001	3.7679	3.7679	3.7629	457.86	420.72	444.59	29.89	26.90	34.35
0.7999	3.7493	3.7422	3.7297	391.61	369.20	397.63	24.09	24.55	29.52
1.0001	3.6895	3.6808	3.6702	366.83	357.93	360.51	22.65	23.13	28.00
DMF - Water (30:70 %w/w)									
0.2001	3.8068	3.7781	3.7631	620.90	601.06	668.23	72.59	55.17	67.92
0.3999	3.7549	3.7339	3.7286	548.61	458.37	486.50	38.38	36.38	41.51
0.6001	3.7257	3.6939	3.6769	425.67	377.86	451.25	28.50	28.02	35.96
0.7998	3.6804	3.6618	3.6362	397.20	338.07	400.00	26.79	24.77	29.70
1.0002	3.6208	3.6107	3.6036	392.93	316.93	367.68	25.44	22.34	27.69

The limiting apparent molal compressibilities  $\phi_k^\circ$  and  $S_k$  for each of the electrolytic solutions have been computed by a least-squares method. From Table 3, it is found that  $\phi_k^\circ$  values are negative for TBAB in DMF-water solutions and decrease on lowering the concentration of water. The negative  $\phi_k^\circ$  values may be due to a loss of compressibility of the solvent due to strong electrostrictive forces of ions. The corresponding  $S_k$  values which indicate the solute-solvent interactions [23] decrease with an increase in temperature.

## 4.3. Apparent Molal Volume

The apparent molal volume behaves in a similar fashion to that of the apparent molal compressibility in the salt solution. The negative values of  $\phi_v$  indicate electrostrictive solvation of ions [24]. To examine the solute-solvent interactions,  $\phi_v^\circ$  values are negative and increase with a rise in temperature and decrease with an increase in the amount of DMF in the mixtures. This indicates the presence of

solute-solvent interactions, and these interactions are strengthened with a rise in temperature and weakened with an increase in the amount of DMF in the mixed solvent.

**Table-3** Limiting apparent molal compressibility ( $\phi_K^0$ ), limiting apparent molal volume ( $\phi_V^0$ ), and constants  $S_K$  and  $S_V$  of TBAB in DMF–water mixtures.

Temperature (K)	$-\phi_K^0 \times 10^8$ ( $\text{m}^2 \cdot \text{N}^{-1}$ )			$S_K \times 10^8$ ( $\text{N}^{-1} \cdot \text{m}^{-1} \cdot \text{mol}^{-1}$ )			$-\phi_V^0$ ( $\text{m}^3 \cdot \text{mol}^{-1}$ )			$S_V$ ( $\text{m}^3 \cdot \text{kg}^{1/2} \cdot \text{mol}^{-3/2}$ )		
	10	20	30	10	20	30	10	20	30	10	20	30
	%	%	%	%	%	%	%	%	%	%	%	%
303	4.50	3.33	3.03	9.30	6.76	6.59	31.04	34.31	22.94	49.57	53.36	46.11
308	4.54	3.12	3.44	9.26	6.34	6.25	33.91	36.47	38.63	51.56	54.39	56.51
313	4.27	4.48	3.43	9.19	7.63	6.81	38.87	46.52	46.13	61.38	68.24	68.23

It is evident from Table 3 that the  $S_V$  values are positive for all temperatures for aqueous mixtures of DMF. Since  $S_V$  is a measure of solute-solute interactions, the results indicate the presence of solute-solute interactions. The  $S_V$  values increase with an increase of temperature and an increase in the amount of DMF in the mixture which results in a decrease in the solvation of ions, i.e., more and more solute is accommodated in the void space left in the packing of large associated solvent molecules with the addition of DMF to the mixture. Similar explanations have also been suggested for ammonium aluminum sulphate and potassium aluminum sulphate in DMSO-water by Parmar [25] and NaI, KI in DMF-propanol by Ali et al. [26].

It is observed from Table 4 that the free volume decreases with an increase in the molality of the salt as well as with an increase in DMF concentration and increases with an increase in temperature. With an increase in salt concentration (at a fixed DMF proportion), a large number of solute molecules go into the bulk solution and the ionic nature of the solute molecules results in closer and closer packing as their number increases, resulting in a decrease in the free volume. This suggests that there are significant interactions between the ions and solvent molecules.

DMF has a strong electronegative oxygen atom which forms electrostatic attraction (hydrogen bond) with the hydrogen atom of the water molecule. As the DMF concentration is increased, additional hydrogen-bonded DMF-water molecules are formed [27], which results in a further reduction of free volume in the mixtures.

Furthermore, there is a progressive increase in the internal pressure with an increase in concentration in 10, 20 and 30 %w/w DMF-water mixtures. The primary effect of dissolving an electrolyte is to lower the compressibility of the solvent molecules. The lowering of the compressibility results in an increase of the ultrasonic velocity, and hence  $\pi_i$  increases with concentration.

As the molality of the electrolyte increases, ion-solvent interactions increase resulting in an overall increase in  $\pi_i$ . As  $\pi_i$  is a measure of interactions [28], its value is found to decrease with temperature at all molalities in all electrolytic solutions. Furthermore, with an increase in the DMF concentration, the internal pressure is found to decrease, as the complex formation is enhanced due to strong ion-solvent interactions.

**Table-4** Free volume ( $V_f$ ), internal pressure ( $\pi_i$ ) and arbitrary constants  $a$ ,  $b$ ,  $c$ , and  $d$  of TBAB in DMF–water mixtures.

Molality of salt (m)	$V_f \times 10^8$ ( $\text{m}^3 \cdot \text{mol}^{-1}$ )			$\pi_i \times 10^{-6}$ (Pa)			$a \times 10^{-10}$ (Pa)	$b \times 10^3$ ( $\text{K}^{-1}$ )	$c \times 10^{13}$ ( $\text{m}^3 \cdot \text{mol}^{-1}$ )	$d \times 10^{-3}$ ( $\text{K}^{-1}$ )
	Temperature (K)			Temperature (K)						
	303	308	313	303	308	313				
DMF - Water (10:90 % w/w)										
0.1999	1.36	1.48	1.55	2784	2694	2585	2.63	7.41	25.87	13.07
0.4000	1.32	1.41	1.50	2793	2712	2594	2.62	7.39	27.44	12.78
0.5999	1.28	1.38	1.47	2808	2734	2612	2.51	7.23	19.32	13.83
0.8000	1.25	1.35	1.42	2824	2756	2636	2.27	6.88	26.24	12.75
1.0002	1.21	1.29	1.39	2856	2773	2674	2.10	6.58	18.10	13.86
DMF - Water (20:80 % w/w)										

0.2002	1.27	1.39	1.47	2698	2584	2514	2.29	7.06	15.11	14.62
0.3999	1.22	1.35	1.43	2712	2593	2536	2.07	6.70	19.92	15.88
0.6001	1.18	1.31	1.38	2736	2612	2578	1.65	5.94	10.27	15.65
0.7999	1.14	1.27	1.32	2744	2628	2594	1.07	4.50	16.60	14.65
1.0001	1.09	1.23	1.29	2761	2653	2623	1.30	5.12	17.61	16.84
DMF - Water (30:70 %w/w)										
0.2001	1.20	1.25	1.36	2615	2564	2494	1.09	4.73	27.05	12.51
0.3999	1.18	1.19	1.33	2631	2582	2508	3.27	6.32	31.42	11.96
0.6001	1.15	1.16	1.28	2645	2594	2516	1.27	4.99	44.82	10.70
0.7998	1.09	1.11	1.25	2673	2609	2534	1.34	5.34	17.18	13.69
1.0002	1.04	1.08	1.21	2694	2618	2565	2.44	7.27	10.58	15.14

The variations of the internal pressure and free volume with temperature at any given concentration can be represented by

$$\pi_i = a \exp(-bT) \quad (10)$$

$$V_f = c \exp(dT) \quad (11)$$

where  $a$ ,  $b$ ,  $c$ , and  $d$  are arbitrary constants.

Thus, a progressive decrease in free volume and an increase in internal pressure in aqueous solutions of TBAB in DMF-water mixtures suggest the existence of ion-solvent interactions, due to which the structural arrangement is considerably affected. The increase in temperature results in a weakening of this interaction.

The viscosity data for tetraalkylammonium bromide in DMF-water solvent mixtures are given in Table 1. It can be seen that the viscosity of the electrolyte solution increases with an increase in the concentration of tetraalkylammonium bromide, and increases with an increasing amount of DMF. The experimental viscosity data have been analyzed using the Jones-Dole equation:

$$\eta / \eta_o = 1 + Am^{1/2} + Bm \quad (12)$$

where  $\eta$  and  $\eta_o$  are the viscosities of the solution and solvent, respectively, and  $m$  is the molal concentration of the solute.  $A$  and  $B$  are characteristic parameters for the solvent and electrolyte. The  $A$ -coefficient represents the contribution from the interionic electrostatic force and can be calculated theoretically if the physical properties of the solvent and the limiting molar conductance are known. The  $B$ -coefficient is an empirical parameter and yields information regarding ion-solvent interactions [29]. It is considered to be a measure of the effective hydrodynamic volume of the solvated ions [30], and to denote the order or disorder introduced by the ions or solute into the solvent structure.

Viscosity  $B$ -coefficients for tetraalkylammonium bromide in DMF-water solvent mixtures were obtained by the least-squares method. The values of the  $A$ -coefficient are found to be negative in all cases, indicating weak ion-ion interactions in the concentration range investigated (Table 5). However, the values of the  $B$ -coefficients for tetraalkyl ammonium bromide are positive. This is identical with the general observation [31] that  $B$ -coefficients are commonly large and almost always positive for salts in non-aqueous solvents. It can be seen from Table 5 that the  $B$ -coefficients of tetraalkylammonium bromide in a DMF-water solvent increase with an increase in the number of carbon atoms in the tetraalkylammonium cations. This suggests the existence of strong ion-solvent interactions [32] in these systems.

**Table-5** Values of the  $A$  and  $B$  parameters of Jones–Dole equation for TBAB in DMF–water mixtures.

DMF % w/w	Temperature (K)					
	$A$ (dm <sup>3/2</sup> .mol <sup>-1/2</sup> )			$B$ (dm <sup>3</sup> .mol <sup>-1</sup> )		
	303	308	313	303	308	313
10	-0.5291	-0.5128	-0.4751	0.6121	0.5979	0.4063
20	-0.7502	-0.6081	-0.2256	0.5811	0.4568	0.3515
30	-0.2969	-0.2482	-0.3043	0.4275	0.3045	0.1780

It has been reported in a number of studies [33, 34] that  $dB/dT$  is a better criterion for determining the structure-making/breaking nature of any solute rather than the  $B$ -coefficient. It is found from Table 5 that the values of the  $B$ -coefficients decrease with an increase in temperature (positive  $dB/dT$ ), suggesting the structure-making tendency of TBAB in the studied solvent systems.

The values of the solvation number for the electrolyte based on the equation are positive at all temperatures, suggesting that the compressibility of the solution will be less than that of the solvent (Table 6). The variation in solvation number with molality and temperature is insignificant. The probability of ions getting closer to the solvent molecules is increased, enhancing the interactions between ion and solvent molecules. The dominance of intermolecular attractions between electrolyte molecules over ion-solvent interactions is due to the insignificant variation in solvation number [24].

Table-6 Solvation number

Molality ( $m$ ) restricted to single digit	$S_n$		
	Temperature (K)		
	303	308	313
	DMF - Water (10:90 %w/w)		
0.2	6.36	6.92	6.56
0.4	5.05	4.42	4.78
0.6	3.85	3.56	3.63
0.8	3.33	3.41	3.58
1.0	2.77	2.66	2.94
	DMF - Water (20:80 %w/w)		
0.2	3.29	3.43	3.90
0.4	2.23	2.55	2.68
0.6	2.37	2.20	2.16
0.8	1.90	1.69	1.70
1.0	1.62	1.62	1.66
	DMF - Water (30:70 %w/w)		
0.2	3.71	2.72	3.54
0.4	2.56	2.07	2.12
0.6	1.87	1.63	1.88
0.8	1.60	1.35	1.58
1.0	1.46	1.24	1.32

## V. CONCLUSION

Density, viscosity and ultrasonic velocity measurements at different temperatures of the electrolytic system demonstrate that

- i. Ion-solvent and ion-ion interactions are present in the system studied.
- ii. Ion-solvent interactions are much pronounced in lower DMF content as well as at lower molalities.
- iii. Ion-ion interactions are very apparent in higher DMF content and at higher salt molality.

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