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Studies on Volumetric and Viscometric properties of Alanine in aqueous Paracetamol solution over a range of temperature (298.15 to 318.15) K.

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Abstract — *The apparent molal volume, partial molal volume, the partial molal volume transfer, partial molal expansivity, viscosity B-coefficients, B-coefficient transfer, ratio of B-coefficient to partial molal volume, temperature derivative of B-coefficient and free energy of activation of viscous flow per mole of solvent and per mole of solute of alanine in aqueous paracetamol solution have been estimated and reported for the first time in literature using the measurement of density and viscosity values of alanine in aqueous paracetamol (0.025, 0.05, 0.075, 0.1) M at 298.15, 303.15, 308.15, 313.15 and 318.15 K. These parameters are inspected in terms of solute-solute and solute-solvent interactions and structure making / breaking ability of solute in the solvent..*

Keywords- *Paracetamol, Partial molal volume, B-Coefficients, Partial molal volume transfer, B-Coefficient transfer.*

I.INTRODUCTION

Drug action at the molecular levels can be understood only by analyzing the physio-chemical properties of drugs in aqueous, protic solvents and aqueous-protic solutions. Generally drugs are made up of organic molecules with both hydrophilic and hydrophobic groups and its actions viz. drug reaching the blood stream, its extent of distribution, its binding to the receptors and finally producing the physiological actions, all depend upon the intermolecular interactions that include ionic or covalent, hydrogen bonding, hydrophilic interactions etc [1-3]. In biophysical chemistry, drug macromolecular interaction is an important phenomenon involving a complex mechanism. Since most of the biochemical process occur in water and in water since the polar groups are hydrated, the intermolecular aggregations of drug molecules through their hydrophobic parts is expected to occur in a way analogous to miscillization [3,4] favouring their limited aqueous solubilization. The thermodynamical and transport properties of drugs in aqueous, protic solvent and aqueous protic solutions provide useful information about absorption of drugs and transport of drugs across biological membranes and these data are used in the field of pharmaceutical and medicinal chemistry[3]. In continuation of our previous studies of amino acids in some aqueous drugs [5-7] we report the thermodynamic study of alanine in aqueous paracetamol solution, in this paper.

Amino acids are universally used as compound models instead of structurally complicated proteins in aqueous salt solution studies to obtain thermodynamic information [5-12]. Alanine is one of the non-essential α-amino acids, used for low blood sugar (hypoglycemia), diarrhea-related dehydration, liver disease, enlarged prostate (benign prostatic hypertrophy, BPH), fatigue, stress, certain inherited disorders including glycogen storage disease, and urea cycle disorders. It also helps the human body convert the simple sugar glucose into energy and eliminate excess toxins from liver. It contains an α-amino group, an α-carboxylic acid group, and a side chain methyl group, which distinguishes it as an aliphatic and nonpolar amino acid.

IUPAC name of Paracetamol is N-acetyl-4-aminophenol which is white in colour broadly used as an analgesic (pain reliever) and antipyretic (fever reducer) drug. The molecular formula is $C_8H_9NO_2$ and the chemical structure is shown in figure 1. Paracetamol consists of a benzene ring core, substituted by one hydroxyl group and the nitrogen atom of an amide group in the para (1,4) pattern which can take part in interactions with alanine. The amide group is acetamide (ethanamide). It is an extensively conjugated system, as the lone pair on the hydroxyl oxygen, the benzene pi cloud, the nitrogen lone pair, the p orbital on the carbonyl carbon, and the lone pair on the carbonyl oxygen are all conjugated [13]. The presence of two activating groups makes the benzene ring highly reactive toward electrophilic aromatic substitution.

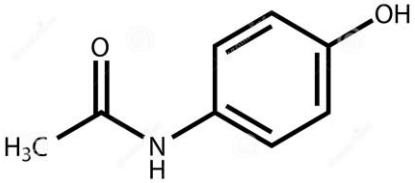

Figure 1 Chemical structure of paracetamol

A detailed research survey shows that no one has so far reported thermodynamic study of alanine in aqueous paracetamol using volumetric and viscometric studies. In this report we are presenting for the first time the new data and results of volumetric and viscometric properties of alanine in aqueous paracetamol, at five different temperatures (298.15 K to 318.15 K) insteps of 5K to provide relevance to drug macromolecules behaviour near physiological temperature.

Different physical thermodynamic parameters like apparent molal volume, V_φ partial molal volume, V_φ^0, the partial molal volume transfer, $V_{\varphi\,tr}^0$, partial molal expansivity, E_2^0, Viscosity B Coefficients, B-Coefficient transfer, ΔB_{tr},

Ratio of B Coefficient to partial molal volume, (B/V_{φ}^{0}), temperature derivative of B-coefficient, dB/dT, and free energy of activation of viscous flow per mole of solvent, $\Delta\mu_1^{0*}$ and per mole of solute of alanine in aqueous paracetamol solution are estimated respectively. All these parameters are used to discuss the solute-solute and solute-solvent interactions occurring in the ternary (alanine + paracetamol + water) system and the structure making/breaking tendency of the solutes in the given solvent.

II.EXPERIMENTAL

Paracetamol (mass fraction purity > 0.990) has been procured from S.D. Fine. Chem. Ltd. Mumbai, alanine (99% assay, Loba Chemie Pvt Ltd), has been used after drying over P_2O_5 in a desiccator for 72 hrs before use. Alanine of molality (0.02, 0.04, 0.06, 0.08 and 0.1) M has been used as solutes in four different molal (0.025, 0.05, 0.075 and 0.1) concentration of aqueous paracetamol solvents, prepared using doubly distilled deionized water with a conductivity of 1.5×10^{-4} $\Omega^{-1}.m^{-1}$. The density and viscosity of the solutions have been measured using single stem pycnometer and suspended ubbelhode viscometer whose procedures have been discussed in detail in our earlier paper [3].

III. RESULTS

The experimental densities and viscosities of the solutions at T= 298.15, 303.15, 308.15, 313.15 and 318.15K are shown in table 1.

Table 1. Density, ρ, and viscosity, η, of solutions of alanine in Paracetamol + water solvents at different temperatures.

m_A /	T/K									
(mol·kg^{-1})	298.15	303.15	308.15	313.15	318.15	298.15	303.15	308.15	313.15	318.15
	ρ x10^{-3} / kg· m^{-3}					η / m.Pa.s				
	Alanine in water									
0	0.99706	0.99560	0.99403	0.99228	0.99032	0.8900	0.7969	0.7187	0.6522	0.5968
0.02	0.99763	0.99616	0.99458	0.99282	0.99083	0.8950	0.8012	0.7224	0.6554	0.5996
0.04	0.99819	0.99670	0.99512	0.99335	0.99133	0.8999	0.8055	0.7262	0.6588	0.6027
0.06	0.99874	0.99723	0.99565	0.99387	0.99183	0.9045	0.8097	0.7301	0.6622	0.6056
0.08	0.99927	0.99771	0.99616	0.99438	0.99232	0.9088	0.8132	0.7332	0.6650	0.6082
0.1	0.99978	0.99818	0.99666	0.99489	0.99280	0.9134	0.8174	0.7366	0.6681	0.6110
	Alanine in 0.025 m_p/(mol·kg^{-1}) aqueous Paracetamol									
0	0.99769	0.99621	0.99463	0.99286	0.99089	0.8994	0.8050	0.7258	0.6585	0.6024
0.02	0.99830	0.99681	0.99521	0.99342	0.99142	0.9047	0.8093	0.7294	0.6616	0.6051
0.04	0.99889	0.99739	0.99577	0.99397	0.99194	0.9095	0.8136	0.7332	0.6651	0.6083
0.06	0.99947	0.99797	0.99633	0.99450	0.99245	0.9143	0.8179	0.7372	0.6683	0.6112
0.08	1.00004	0.99853	0.99687	0.99500	0.99294	0.9186	0.8214	0.7402	0.6711	0.6134
0.1	1.00059	0.99907	0.99740	0.99550	0.99341	0.9230	0.8256	0.7434	0.6742	0.6164
	Alanine in 0.05 m_p /(mol·kg^{-1}) aqueous Paracetamol									
0	0.99837	0.99689	0.99530	0.99354	0.99156	0.9075	0.8124	0.7324	0.6644	0.6079
0.02	0.99900	0.99752	0.99591	0.99412	0.99212	0.9124	0.8166	0.7359	0.6674	0.6105
0.04	0.99962	0.99812	0.99650	0.99470	0.99266	0.9167	0.8210	0.7398	0.6708	0.6137
0.06	1.00023	0.99872	0.99709	0.99527	0.99320	0.9219	0.8250	0.7438	0.6740	0.6166
0.08	1.00083	0.99931	0.99768	0.99582	0.99374	0.9262	0.8287	0.7467	0.6768	0.6189
0.1	1.00141	0.99989	0.99825	0.99636	0.99426	0.9306	0.8327	0.7500	0.6800	0.6218
	Alanine in 0.075 m_p /(mol·kg^{-1}) aqueous Paracetamol									
0	0.99904	0.99756	0.99596	0.99419	0.99221	0.9171	0.8205	0.7395	0.6708	0.6133
0.02	0.99969	0.99820	0.99658	0.99480	0.99278	0.9224	0.8246	0.7427	0.6737	0.6159
0.04	1.00033	0.99882	0.99719	0.99538	0.99334	0.9273	0.8291	0.7469	0.6771	0.6190
0.06	1.00095	0.99942	0.99778	0.99595	0.99390	0.9321	0.8330	0.7509	0.6803	0.6219
0.08	1.00156	0.99998	0.99835	0.99653	0.99444	0.9364	0.8368	0.7536	0.6832	0.6242
0.1	1.00215	1.00055	0.99891	0.99709	0.99498	0.9410	0.8408	0.7569	0.6864	0.6272
	Alanine in 0.10 m_p /(mol·kg^{-1}) aqueous Paracetamol									
0	0.99973	0.99824	0.99663	0.99485	0.99287	0.9260	0.8286	0.7469	0.6773	0.6194
0.02	1.00040	0.99890	0.99727	0.99547	0.99346	0.9312	0.8325	0.7499	0.6800	0.6219
0.04	1.00106	0.99955	0.99790	0.99608	0.99404	0.9362	0.8372	0.7542	0.6835	0.6250
0.06	1.00170	1.00018	0.99852	0.99668	0.99461	0.9410	0.8411	0.7582	0.6867	0.6279
0.08	1.00233	1.00080	0.99910	0.99723	0.99517	0.9452	0.8449	0.7610	0.6894	0.6302

0.1	1.00295	1.00140	0.99969	0.99781	0.99572	0.9500	0.8489	0.7641	0.6927	0.6332

m_A molality of alanine

m_p molality of paracetamol

The apparent molal volume, V_φ of alanine in aqueous paracetamol solution has been calculated from density (Table 1) by using the following relation [5],

$$V_\varphi = (M/\rho)-1000\,(\rho-\rho_0)/m\,\rho\,\rho_0 \quad (1)$$

Where M is the molal mass of the solute, m is the molality of solute (alanine) ρ and ρ_0 are the densities of the solution and the solvent (aqueous paracetamol) respectively.

The values of partial molal volume, V_φ^0 and the slope, S_v have been evaluated by least squares fitting of V_φ verses 'm' from the following equation [5],

$$V_\varphi = V_\varphi^0 + S_v m \quad (2)$$

Where V_φ^0 is the infinite dilution value that is equal to the partial molal property at infinite dilution and S_v is the experimental slope. The V_φ^0 values of alanine in water at the studied temperatures agree fairly well with literature values (Table 2) thus validating our experimental procedures.

The partial molal volumes of transfer at infinite dilution of alanine from water to aqueous paracetamol solutions have been calculated using the following relation [5]

$$V_{\varphi\ tr}^0 = V_{\varphi\ \text{in aq.-Paracetamol}}^0 - V_{\varphi\ \text{in water}}^0 \quad (3)$$

Where $V_{\varphi\ \text{in water}}^0$ is the partial molal volume of alanine in water and $V_{\varphi\ \text{in aq.Paracetamol}}^0$ is the partial molal volume of alanine in aqueous paracetamol (Table 2). The values of $V_{\varphi\ tr}^0$ of alanine in water to aqueous paracetamol solution are included along with standard deviation of linear regression, σ in table 2 and are graphically represented in figure 2.

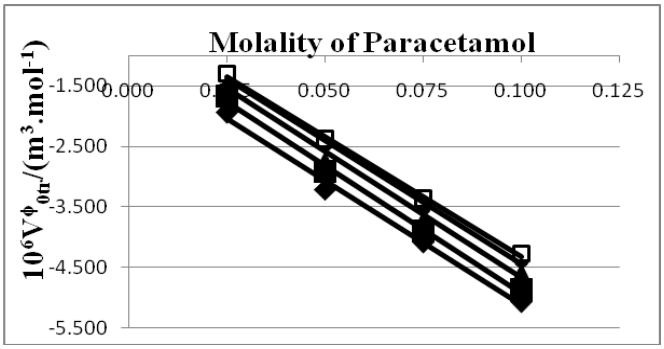

Figure 2. Variations of transfer volume, $V_\phi^0 t_r$ vs. Molality of Paracetamol, M_s, for α –alanine in Paracetamol + water solutions at temperatures, T/K=298.15, ♦; T/ K=303.15, ■; T/K=308.15, ▲; T/K=313.15, ●; T/K=318.15, □.

Table 2. Partial molal volume, V_φ^0, and Transfer volumes, $V_{\varphi\ tr}^0$, Viscosity B coefficients, B, and transfer B coefficients, ΔB, Ratio of B coefficient to partial molal volume, B/V_φ^0, free energy of activation of solvent, $\Delta\mu_1^{0*}$, free energy of activation of solute, $\Delta\mu_2^{0*}$, and standard deviations of linear regression, σ for alanine in aqueous Paracetamol solution at different temperatures.

	T/K						T/K			
Property	298.15	303.15	308.15	313.15	318.15	298.15	303.15	308.15	313.15	318.15
	Alanine in water					Literature values of Alanine in water				
$10^6 .V_\varphi^0 /(m^3\cdot mol^{-1})$	60.298	60.601	61.445	62.147	63.818	60.12[14]	60.6[15]	60.88[16]	62.9[17]	61.46[18]
10 . σ for V_φ^0	0.12	0.2	0.078	0.058	0.068					
$10^3 .B/(m^3\cdot mol^{-1})$	0.259	0.254	0.249	0.246	0.241	0.258[19]		0.250[20]	0.247[21]	0.238[21]
σ for B	0.031	0.048	0.062	0.052	0.042					
B / V_φ^0	4.30	4.19	4.05	3.96	3.78					
$\Delta\mu_1^{0*}/(kJ\cdot mol^{-1})$	9.16	9.04	8.93	8.83	8.74					
$\Delta\mu_2^{0*}/(kJ\cdot mol^{-1})$	50.49	50.34	50.26	50.42	50.42					
	Alanine in 0.025 / 0.05 m_p /($mol\cdot kg^{-1}$) aqueous Paracetamol									
$10^6 .V_\varphi^0 /(m^3\cdot mol^{-1})$	58.356	58.92	60.016	60.81	62.528	57.087	57.672	58.731	59.692	61.43
10 . σ for V_φ^0	0.101	0.134	0.129	0.155	0.122	0.052	0.252	0.181	0.138	0.172
$10^6 .V_{\varphi\ tr}^0 /(m^3\cdot mol^{-1})$	-1.942	-1.681	-1.429	-1.337	-1.290	-3.211	-2.929	-2.714	-2.455	-2.388
$10^3 .B/(m^3\cdot mol^{-1})$	0.256	0.250	0.244	0.240	0.234	0.255	0.248	0.242	0.238	0.232
σ for B	0.036	0.05	0.081	0.052	0.077	0.045	0.041	0.087	0.042	0.07
$\Delta B .10^3 / (m^3\cdot mol^{-1})$	-0.003	-0.004	-0.005	-0.006	-0.007	-0.004	-0.006	-0.007	-0.008	-0.009

B / V_φ^0	4.39	4.24	4.07	3.95	3.74		4.47	4.30	4.12	3.99	3.78
$\Delta\mu_1^{0*}$/ (kJ·mol^{-1})	9.20	9.07	8.96	8.86	8.77		9.22	9.10	8.99	8.89	8.80
$\Delta\mu_2^{0*}$/ (kJ·mol^{-1})	49.76	49.47	49.27	49.28	49.13		49.34	48.94	48.72	48.75	48.60
	Alanine in 0.075 / 0.1 m_p /(mol·kg^{-1}) aqueous Paracetamol										
10^6 .V_φ^0 /(m^3·mol^{-1})	56.209	56.683	57.74	58.634	60.44		55.233	55.726	56.875	57.763	59.55
10 . σ for V_φ^0	0.075	0.159	0.103	0.364	0.095		0.067	0.075	0.217	0.26	0.00
10^6 .$V_{\varphi\,tr}^0$/(m^3·mol^{-1})	-4.089	-3.918	-3.705	-3.513	-3.378		-5.065	-4.875	-4.57	-4.384	-4.268
10^3.B /(m^3·mol^{-1})	0.254	0.247	0.240	0.236	0.230		0.253	0.246	0.238	0.234	0.228
σ for B	0.033	0.042	0.115	0.034	0.061		0.04	0.055	0.124	0.054	0.06
ΔB .10^3 / (m^3·mol^{-1})	-0.005	-0.007	-0.009	-0.01	-0.011		-0.006	-0.008	-0.011	-0.012	-0.013
B / V_φ^0	4.52	4.36	4.16	4.02	3.81		4.58	4.41	4.18	4.05	3.83
$\Delta\mu_1^{0*}$/ (kJ·mol^{-1})	9.26	9.14	9.02	8.92	8.83		9.29	9.17	9.06	8.95	8.86
$\Delta\mu_2^{0*}$/ (kJ·mol^{-1})	49.00	48.58	48.22	48.23	48.08		48.66	48.23	47.74	47.75	47.59

[a] Ref 14. [b] Ref 15. [c] Ref 16. [d] Ref 17. [e] Ref 18. [f] Ref 19. [g] Ref 20. [h] Ref 21.

The temperature dependence of V_φ^0 [22] for alanine in aqueous paracetamol solution can be expressed by the equation (4).

$$V_\varphi^0 = a + bT + cT^2 \quad (4)$$

Where a, b and c may be estimated by the least squares fitting of partial molal volume in the above equation. The value $\partial^2V_\varphi^0/\partial T^2$, called Hepler's constant [22,23] gives the information about the structure making / breaking properties of solute in aqueous paracetamol solution. On the basis of these criteria, a structure making solute will exhibit positive ($\partial^2V_\varphi^0/\partial T^2$) values and structure breaking solute will show opposite trend. The values of Hepler's constant are given in table 3.

The values of partial molal expansivity [22] have been calculated from the partial molal volume using the relation (5) and are included in table 3.

$$E_2^0 = (\partial V_\varphi^0/\partial T)_P \quad (5)$$

The experimentally measured viscosity values are used to estimate the viscosity B-Coefficients by fitting the values to the Jones-Dole equation [24] by a least squares method as follows.

$$\eta_r = \eta / \eta_0 = 1 + B\cdot c \quad (6)$$

where η_r is the relative viscosity of the solution, η and η_o are the viscosities of solution and the solvent (paracetamol + water) respectively. m is the molality of alanine in aqueous paracetamol solution , B is the Jones–Dole coefficients and, c is the molality (calculated from molality data), respectively. The estimated values of viscosity B-Coefficients of alanine in water at the studied temperatures along with the standard derivations of linear regression, σ are listed in table 2 agree fairly well with literature values, thus validating experimental procedures [19-21]. The temperature derivative of B Coefficient (dB/dT) which gives the structure / breaking property of the solute has also been calculated and included in the table 3.

Table 3. Partial molal expansivity E_2^0, Temperature derivative of B-coefficient, dB/dT, and Hepler's constants ($\partial_2V_\varphi^0/\partial T^2$), of alanine in aqueous Paracetamol solution at different temperatures.

m_p/	10^6 E_2^0/	$\partial^2V_\varphi^0/\partial T^2$ /	dB/dT /
(mol·kg^{-1})	(m^3 ·mol^{-1}·K^{-1})	(m^6. mol^{-2} · k^{-2})	(m^3 ·mol^{-1}·K^{-1})
0.00	0.171	0.00741	-0.00088
0.025	0.204	0.00573	-0.00108
0.05	0.214	0.00631	-0.00112
0.075	0.208	0.00715	-0.00118
0.1	0.213	0.00665	-0.00124

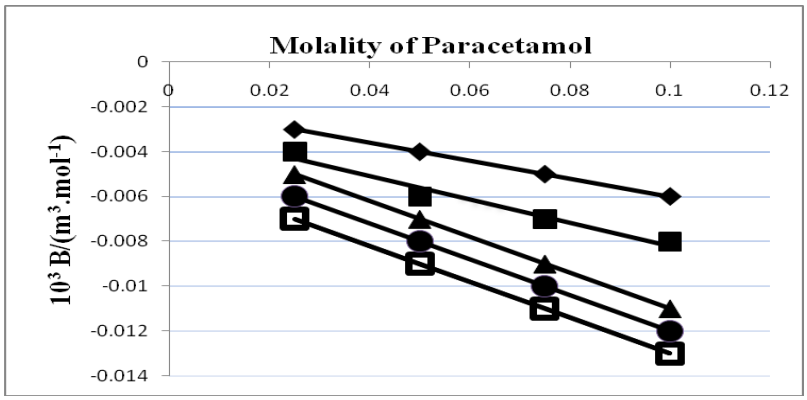

Figure 3. Variations of Jones-Dole coefficient, B vs. Molality of Paracetamol, M_s, for alanine in Paracetamol + water solutions at temperatures, T/K=298.15, ♦; T/K =303.15, ■; T/K=308.15, ▲; T/K=313.15, ●; T/K=318.15, ◘;

The ratio of viscosity B-Coefficients to the partial molal volume V_φ^0, ie., B/V_φ^0 can be used to judge the solvation of any solute are evaluated and are listed in table 2.

The viscosity B-coefficients of transfer, ΔB_{tr} of alanine from water to aqueous paracetamol solutions has been calculated using the following relation

$$\Delta B_{tr} = B_{\text{in aq.-Paracetamol}} - B_{\text{in water}} \qquad (7)$$

and are shown in table 2.

Furthermore, the viscosity data are used to estimate the free energy of activation per mole of the solvent ($\Delta\mu_1^{0*}$) and solute ($\Delta\mu_2^{0*}$) as suggested by Feakins et al.[25] and Eyring et al. [26] using the following Eqns. (8), (9) and (10)

$$B = (\bar{V}_1^0 - \bar{V}_2^0)/1000 + \bar{V}_1^0/1000\, RT(\Delta\mu_2^{0*} - \Delta\mu_1^{0*}) \qquad (8)$$

$$\Delta\mu_1^{0*} = RT \ln(\eta_0 \bar{V}_1^0 / hN) \qquad (9)$$

Equation (9) can be rearranged as

$$\Delta\mu_2^{0*} = \Delta\mu_1^{0*} + RT/\bar{V}_1^0[1000\, B - (\bar{V}_1^0 - \bar{V}_2^0)] \qquad (10)$$

Where $\bar{V}_1^0 = (\Sigma x_i m_i / \rho)$ is the mean value of the solvent and $\bar{V}_2^0 = V_\phi^0$ is the partial molal volume at infinite dilution of the solute, h is Plank's constant, N_A is Avogadro's number, η_o is the viscosity of the solvent and R is the gas constant. The calculated values of $\Delta\mu_1^{0*}$ and $\Delta\mu_2^{0*}$ are also given in table 2.

Thermodynamic transfer functions of amino acids may be expressed by the Mc Millan-Mayer theory of solutions [8,27,28] which permits the formal separation of the effects due to the interaction between the pairs of the solute molecules and those due to interactions between three or more molecules by the equations (11) and (12).

$$V^0_{\varphi\ tr\ \text{(water to aqueous Paracetamol solution)}} = 2V_{AB}\, m_B + 3V_{ABB}\, m_B^2 + \text{----} \qquad (11)$$

$$\Delta B_{tr\ \text{(water to aqueous Paracetamol solution)}} = 2\eta_{AB}\, m_B + 3\,\eta_{ABB}\, m_B^2 + \text{----} \qquad (12)$$

When A stands for alanine and B stands for paracetamol and m_B is the molality of paracetamol in water (cosolute). The constants V_{AB} / η_{AB}, V_{ABB} / η_{ABB} are pair and triplet volumetric/viscometric interaction parameters obtained by fitting data to equation (11)&(12). The evaluated parameters V_{AB} / η_{AB}, V_{ABB} / η_{ABB} for volumes and viscosities are summarized in table 4.

Table 4. Values of pair (V_{AB}, η_{AB}) and triplet (V_{ABB}, η_{ABB}) of alanine in aqueous Paracetamol solution at different temperatures.

T/K	$V_{AB} \times 10^6$ / $m^3.mol^{-2}.kg$	$V_{ABB} \times 10^6$ / $m^3.mol^{-3}.kg^2$	$10^3\ \eta_{AB}$/ $m^3.mol^{-2}.kg$	$10^3\ \eta_{ABB}$/ $m^3.mol^{-3}.kg^2$
	From volume		From viscosity	
298.15	-42.230	121.053	-0.0650	0.2578
303.15	-36.075	82.413	-0.0900	0.3556
308.15	-30.725	52.347	-0.1075	0.3867
313.15	-28.055	41.573	-0.1300	0.5156
318.15	-27.070	39.307	-0.1525	0.6444

DISCUSSION:

On volumetric data:

It is observed from table 1 that the density of the ternary system increases with increase of concentration of solute and the temperature. This may be due to shrinkage of the volume thereby exhibiting a presence of strong solvent

interactions. In other words, the increase in density is attributed to the enhanced structure of solvent mixture due to the added solute (alanine) [29].

An analysis of table 2 brings out that V_φ^0 values are positive indicating the presence of strong solute– solvent interactions and weak solute–solute interactions in these systems [30]. The positive values of V_φ^0 may be attributed to their hydration behavior, due to the following interactions in these systems [11]: namely (a) The terminal groups of zwitterions of amino acids, NH_3^+ and COO^- are hydrated in an electrostatic manner whereas, hydration of R group depends on its nature, which may be hydrophilic, hydrophobic, or amphiphilic; (b) Electrostriction of NH_3^+ group is 10 times greater than COO^-group; and (c) The overlap of hydration co-spheres of terminal NH_3^+ and COO^-groups and of adjacent groups results in volume change.

Moreover, the V_φ^0 values increase with the increase in concentration of solutes which are related to the reduction in the electrostriction at terminals. The solvation effect of alanine zwitterions in the solvent [31-34] may be attributed by the increase in V_φ^0 values (Table 2) with increase in temperature.

Solute-solvent interactions and the structure making or breaking properties of the solute may also be inferred from the values of partial molal expansivity E_2^0. For a structure making solute the partial molal expansivity values are positive while for structure breaking solutes the values are opposite. In the present case, the positive values of partial molal expansivity (Table 3) substantiate the structure making [35] property of the solute (alanine) in aqueous paracetamol solvent.

The structure maker properties of the solute [36] is further substantiated by the positive values of second derivatives of V_φ^0 viz $(\partial^2 V_\varphi^0/\partial T^2)_p$ (Table 3). This further supports that the charged end groups of amino acids are the predominant factors for the feature of temperature dependence of V_φ^0 of amino acids [11].

The values of transfer volumes, $V_{\varphi\,tr}^0$ are negative and decrease monotonically (Figure 2) with the molal concentration of paracetamol and increase with temperature are shown in table 2. The value of $V_{\varphi\,tr}^0$ is theoretically free from solute-solute interaction and it provides information regarding solute-solvent interactions [37]. The negative value $V_{\varphi\,tr}^0$ for the alanine in aqueous paracetamol solutions could be explained by the co-sphere overlap model developed by Friedman and Krishnan [38]. The types of the interaction occurring between alanine and aqueous paracetamol can be classified as follows [39,40].

a) The hydrophilic–ionic interaction between OH groups of paracetamol and zwitterions of alanine.
b) Hydrophilic–hydrophilic interaction the OH groups of paracetamol and NH groups in the side chain of acid alanine mediated through hydrogen bonding.
c) Hydrophilic–hydrophobic interaction between the OH groups of paracetamol molecule and non-polar ($-CH_3$) in the side chain of alanine molecule.
d) Hydrophobic–hydrophobic group interactions between the non-polar groups of Paracetamol and non-polar ($-CH_3$) in the side chain of alanine molecule.

Generally the values of $V_{\varphi\,tr}^0$ increase due to reduction in the electrostriction at terminals by positive contribution from the interactions of type (a) and (b), whereas it decreases due to disruption of side group hydration by that of the charged end by negative contribution from the interactions of type (c) and (d) mentioned earlier [11]. From the observed negative $V_{\varphi\,tr}^0$ values the dominance of hydrophilic–hydrophobic group and hydrophobic–hydrophobic group interactions is observed in the studied systems [8].

On viscometric property:

From the table 1, it is observed that viscosity values increase with increase in concentration of solute (alanine). When a solute is dissolved in a solvent, some of the solvent molecules are attracted to the solute as the result of solute-solvent interaction and thus the viscosity is increased [11]. Generally, the increase in viscosity of the solution on addition of solute indicates the structure making aspects of solutes [41]. The information about the solvation of the solutes and their effects on the structure of the solvent in the near environment of the solute molecule is provided by the viscosity B-coefficients. As an empirical term the viscosity B-coefficient has been calculated and it depends upon solute-solvent interactions and on the relative size of the solute and solvent molecules. The obtained positive values of B-coefficient in the present systems points out the strong solute-solvent interactions and also the solute's structure making ability [42].

Rather than simply giving information pertaining to viscosity B coefficients, the sign of (dB/dT) has been reported widely in literature to identify the structure making / breaking property of the solute in the solvent media [42]. As the *B* values decrease with increase in temperature (Figure 3), their first derivatives of temperature (dB/dT) are negative (Table 3) there by showing the structure making ability of amino acids (alanine). Thus we can conclude that alanine is a structure maker in aqueous paracetamol solutions. These results excellently agree with the conclusions drawn from volumetric studies.

Furthermore, the solvation of any solute can be gauged from the magnitude of B/V_φ^0 and are listed in table 2. A value between 0 and 2.5 indicates the unsolvated spherical species; and any higher value (>2.5) is an indication of solvated ones. In the present case, the values of B/V_φ^0 is > 2.5 substantiating the presence of solvated [43] spherical species in the reported systems.

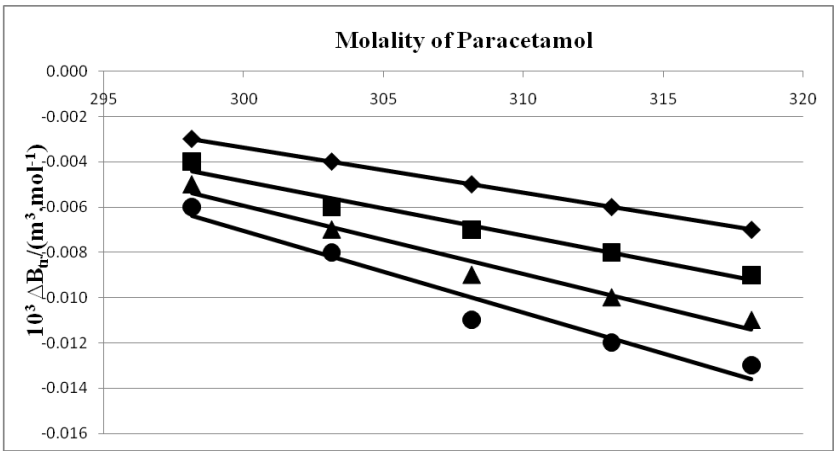

Figure 4. Variations of Jones-Dole coefficient, ΔB_{tr} vs. Molality of Paracetamol, M_s, for alanine in Paracetamol + water solutions at temperatures, T/K=298.15, ♦; T/ K=303.15, ■; T/K=308.15, ▲; T/K=313.15, ●.

Analysis of figure 4 shows that ΔB_{tr} are negative and decreases with concentration and temperature in all cases. The nature of variation in ΔB_{tr} may be attributed to the dominance of hydrophobic –hydrophobic interactions over the hydrophilic– hydrophilic interactions [36].

Moreover, viscous flow's activation parameters are obtained by utilizing B-Coefficients [44]. The values of $\Delta\mu_2^{0*}$ are positive and larger than $\Delta\mu_1^{0*}$(Table 2) indicating the structure making ability of the solute [25] and thus supplements our earlier findings by $\partial^2 V_\varphi^0/\partial T^2$ and d*B*/d*T* studies. Also, larger $\Delta\mu_2^{0*}$ values describe the presence of stronger solute-solvent interactions. The positive values of V_{ABB}/η_{ABB} indicate that the triplet interactions are stronger the doublet interactions V_{AB}/η_{AB} in the studied system.

V. CONCLUSION

The density and viscosity of alanine in aqueous paracetamol solution have been measured and reported for different concentrations and at five different temperatures. Several thermodynamic parameters have been calculated and the present study indicates the existence of strong solute–solvent interactions.

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