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RESEARCH ARTICLE

VISCOMETRIC, VOLUMETRIC AND THERMOACOUSTIC BEHAVIOUR OF AMINO ACIDS IN UREA(aq)

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Abstract

Measurement of density, viscosity, sound speed and refractive index has been done by established experimental procedures using pre-calibrated bicapillary pyknometer, pre-calibrated Ostwald's viscometer, Ultrasonic interferometer and Abbe's Refractometer respectively for the solutions of amino acid L-Arginine and L-Threonine with Urea (aq) as solvent so as to determine the type of interactions. Physical properties like density, viscosity and sound speed are useful for computing the derived parameters viz. Apparent Molal Volume (ϕ_v), Adiabatic Compressibility (β), Apparent Molal Compressibility (ϕ_k), Relative Association (R_A), Hydration Number (H_n), Viscous Relaxation Time (τ), Specific Acoustic Impedance (Z), Intermolecular Free Length (L_f), Limiting Apparent Molal Volume (ϕ_v°), Limiting Apparent Molal Compressibility (ϕ_k°), Experimental Slope (S_v^* and S_k^*), A and B coefficient of Jones-Dole Equation, Free energy of activation of viscous flow per mole of solvent ($\Delta\mu_1^{\circ\#}$) and Free energy of activation of viscous flow per mole of solute ($\Delta\mu_2^{\circ\#}$) which throw light on interactions between unlike components of multicomponent mixtures. Molar Refractivity (R_D) has also been computed from Refractive Index data using Lorentz-Lorenz equation. The results are recorded at 298K, 308K in tabular and graphics manner to assess the influence of temperature on interactions between the components.

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INTRODUCTION

Ultrasonic waves travel through materials under the influence of sound pressure, the velocity of which is controlled by the elastic moduli and the density of material, which in turn are governed by the amount of various phases present and the damage in the material. Ultrasonics can be directly related to thermodynamic parameters without using sophisticated techniques.

Amino acids are the chemical units or "building blocks" of the body that make up proteins. All naturally occurring amino acids are L-amino acids which can be metabolized by our enzymes.

L-Threonine an essential amino acid helps maintain proper protein balance in the body; is important for the formation of collagen, elastin and tooth enamel; aids liver and Lipotropic function when combined with Aspartic Acid and Methionine; prevents the buildup of fat in the liver; assists metabolism and assimilation (Riyazuddeen et al., 2012)

L-Arginine a non essential amino acid is considered "The Natural Viagra" by increasing blood flow to the penis; retards the growth of tumors and cancer by enhancing the immune system; increases the size and activity of the thymus gland, which manufactures T cells, crucial components of the immune system; aids in liver detoxification by neutralizing ammonia; reduces the effects of chronic alcohol toxicity; used in treating sterility in men by increasing sperm count; aids in weight loss because it facilitates an increase in muscle mass and a reduction of body fat. The handling of urea by the kidneys is a vital part of human metabolism. Besides its role as carrier of waste nitrogen, urea also plays a role in the countercurrent exchange system of the nephrons that allows for reabsorption of water and critical ions from the excreted urine (Zhu et al., 2014).

MATERIALS AND METHODS:

Analytical range (AR) grade L-Arginine and L-Threonine, with minimum assay of 99% obtained from Himedia was used as such without further purification. Distilled water was used to make the solutions. Aqueous solution of Urea 0.01M (minimum assay 99%, Qualigens) was prepared w/v and used as such on the day they were prepared. The concentration range selected for amino acid is 0.1030 m to 1.029 m (upto maximum solubility) with a precision of $\pm 1 \times 10^{-4}$g on electronic digital balance. Density was determined using precalibrated bicapillary pyknometer having two limbs with 50 equal divisions with an error value up to ±0.06% (Mehra et al., 2011), viscosity by the use of precalibrated Ostwald's viscometer, error up to ±0.07% (Yadav et al., 2011). Sound speed was measured using Ultrasonic interferometer (Mittal Enterprises, New Delhi, Model F-81) working at a fixed frequency of 2 MHz up to an error of ±0.04% and refractive index by precalibrated Abbe's refractometer measuring upto an error of ±0.01% (Mehra et al., 2013). All the experiments have been carried out at constant temperature in a refrigerated water bath maintaining temperature up to ±0.1°C. The solutions were stored in airtight bottles so as to minimize absorption of atmospheric moisture. The experimentation is carried out at different temperatures viz. 298K, 308K so as to study the interactions more precisely.

FORMULAE:

$$\phi_v = \frac{1000(\rho_o - \rho)}{m\rho_o\rho} + \frac{M}{\rho} \qquad \beta = \frac{1}{u^2\rho} \qquad \phi_k = \frac{1000(\rho_o\beta - \rho\beta_o)}{m\rho\rho_o} + \frac{\beta M}{\rho}$$

$$R_A = (\rho/\rho_o)(u_0/u)^{1/3} \qquad H_n = \left[\frac{n_1}{n_2}\right]\left[1 - \frac{\beta}{\beta_o}\right] \qquad \tau = \frac{4\eta}{3\rho u^2}$$

$$L_f = K * \sqrt{\beta} \qquad Z = u\rho$$

Masson empirical relation (Masson, 1929) $\phi_v = \phi_v^\circ + S_v^* \sqrt{m}$ $\phi_k = \phi_k^\circ + S_k^* \sqrt{m}$

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

Jones-Dole equation (Jones et al., 1929) $\frac{\eta}{\eta_o} = 1 + Am^{1/2} + Bm$

Where ρ=density of solution; ρ_0= density of solvent; η= viscosity of solution; η_o= viscosity of solvent; m= concentration in mol Kg^{-1}; M= Molecular weight of amino acid, x_i= mole fraction; u= sound speed of solution; u_o= sound speed of solvent

RESULTS AND DISCUSSIONS:

The densities (ρ) (Table 1) and viscosities (η) (Table 2) of the solutions of L-Arginine and L-Threonine each with Urea(aq) increase with the increase in concentration of amino acids due to association occurs between solute and

solvent molecules (Malasane, 2013) and decrease with the rise of temperature can be credited to increase in thermal energy of the system that diminishes the intermolecular forces (Roy et al., 2009)

Sound speed (u) for solutions of L-Arginine and L-Threonine each with Urea(aq) increases with the increase of concentration as a result of greater association among the molecules of solutions and as also with temperature (Table 3). With the increase of temperature Hydrogen bonds of long range order among solvent molecules break and more monomeric solvent molecules are created. The amino acid molecules form more compact structures with solvent molecules. This functions as material medium for sound waves and thus sound speed increases with temperature (Kumar, 2012).

Apparent Molal Volume (ϕ_v) is observed to increase with square root of concentration as also with temperature (Table 4) for the solutions of L-Arginine and L-Threonine each with Urea(aq) as a result of shrinking of the voids in solvent structure (Mehra et al., $2012)_a$ due to increased intermolecular H-bonding introduced with the addition of amino acid (Dash et al., 2012).

Adiabatic Compressibility (β) for solutions of L-Arginine and L-Threonine each with Urea(aq) decrease with increase of concentration and also with rise of temperature (Fig.1, 2). The addition of amino acid causes the solvent structure to break (due to electrostrictive forces of zwitterions of amino acids) and come more in contact with the solvent molecules thus decreasing the number of free solvent molecules in the bulk layer. With the increase of temperature the mean distance between molecules tend to increase with a corresponding decrease in compressibility (Mehra et al., 2010_a, Dhir, 2011)

Apparent Molal Compressibility (ϕ_k) values are negative for all the solutions of amino acids with Urea(aq) symbolizing strong electrostatic forces in the vicinity of ions and solvation of ions (Pal et al., 2009). The negative values decrease with square root of concentration and increase with rise of temperature (Fig. 3, 4). More negative is the value of ϕ_k, larger is the number of solvated amino acid molecules experiencing denaturation effect of urea (Thirumaran et al., 2014)

Relative Association (R_A) increases with the increase of concentration and decreases with the rise of temperature for all the four solutions (Fig. 5, 6). R_A is affected by two factors (i) breaking up of solvent aggregates on addition of electrolyte; (ii) hydration of ions by solvent molecules. Former effect causes R_A to decrease and the latter effect causes it to increase (Sumathi et al., 2013). Increase in R_A with concentration of amino acid explains that solute-solvent interaction is higher than breaking up of solvent aggregates. Increase in temperature weakens the intermolecular bond strength and release more solvent molecules thus leading to increase in R_A.

Hydration number (H_n) decreases with increase in concentration and increases with the increase of temperature (Table 5). With the increase in amino acid concentration, the magnitude of the electrostatic forces increases thus breaking the solvent structure and the solute molecules are surrounded by higher number of solvent molecules making hydration layer even less compressible (Thirumaran et al., 2011),. Rise in temperature causes weakening of the bonds liberating more free solvent molecules causing H_n to increase (Burakowski et al., 2008)

The increase in Viscous Relaxation Time (τ) with concentration at all temperatures (Table 6) can be explained due to interactions between amino acid and solvent molecules and reinforcement of H-bonds. At high temperature, Hydrogen bonds weaken due to thermal vibration and structure breaking effect predominates over Hydrogen bond formation and hence τ decreases with temperature (Wadekar, 2013).

Specific Acoustic Impedance (Z) increases with concentration and also with temperature for solutions of L-Arginine and L-Threonine each with Urea(aq) (Fig. 7, 8). This may be due to the variation of pressure from particle to particle (Mehra et al., 2012_b).

Intermolecular Free Length (L_f) decreases with the increase in concentration of solute and increases with the increase of temperature for L-Arginine and L-Threonine solutions each with Urea(aq) (Fig. 9, 10). The decreasing compressibility brings the molecules to closer approach resulting in decreasing L_f with increasing concentration. Increasing temperature leads to increase in mean free distance between molecules and increase of free length (Praharaj et al., 2012).

Gibb's free energy change (ΔG) increases with concentration of amino acids at all temperatures for all solutions and decrease with temperature for L-Arginine+Urea(aq) but increase with temperature for L-Threonine+Urea(aq) solution (Fig. 11, 12). Increase in values with concentration might be due to closer approach of unlike molecules with the formation of H-bonding also indicating the need for less time for rearrangement of molecules in solution (Shirts et al., 2005). Temperature increase affects the intermolecular bond strength and causes variation (Gerstner,1994).

Enthalpy change (ΔH) (obtained from the intercept of the plot of ΔG vs T) values are negative for L-Threonine+Urea(aq) solution and the negative values increase with concentration (Fig. 13). Increase in positive ΔH values observed for solutions of L-Arginine are indicative of increase in solute-solvent interactions (Baldwin., 2007).

Entropy change (ΔS) values (obtained from the slope of the plot of ΔG vs T) are all negative for L-Arginine solutions with Urea(aq) but positive for L-Threonine +Urea(aq) solution. The negative values of ΔS increases with concentration (Fig. 14) exhibit increase in ordered arrangement in the system whereas the increasing positive values of ΔS for L-Threonine+Urea(aq) reveal decrease in order of the system (Freire et al., 1996).

Free energy of activation of viscous flow per mole of solute ($\Delta\mu_2^{\circ\#}$) values are higher than Free energy of activation of viscous flow per mole of solvent ($\Delta\mu_1^{\circ\#}$) for all solutions with Urea(aq) (Table 7) suggesting that formation of transition state is less favoured in the presence of amino acid (Banipal et al., 2008, Rajagopal et al., 2011).

Limiting Apparent Molal Volume (ϕ_v°) (obtained from the intercept of the plot between ϕ_v vs $m^{1/2}$ from Mason's equation is a measure of solute-solvent interactions) the values are positive and increasing (Table 7) signifying the existence of strong solute-solvent interactions and indicating reduction in polarization at terminals with increase of temperature (Ali et al., 2007)$_a$.

Positive values of S_v^* obtained from the slope of the plot of ϕ_v vs $m^{1/2}$ from Mason's equation represent solute-solute interactions for solutions of L-Arginine but negative values for L-Threonine+Urea(aq) solution (Table.7) show that interactions in L-Threonine+Urea(aq) solutions are less significant. The increase in temperature produces a marked effect on the solute-solute interactions (Ali et al., 2007)$_b$.

Limiting Apparent Molal Compressibility (ϕ_k°) (obtained from the intercept of the plot between ϕ_K vs $m^{1/2}$ from Mason's equation) is also a measure of solute-solvent interactions (Table 7). The increasing negative values with temperature for all solutions indicate the loss of structural compressibility due to disruption of solute and existence of solute-solvent interactions. Positive values of S_k^* (Mason's equation) increasing with rise in temperature (obtained from the slope of the plot of ϕ_K vs $m^{1/2}$) (Table 7) represents the existence of solute-solute interactions alongwith solute-solvent interactions (Mehra et al., 2010)$_b$.

B-coefficient of Jones-Dole equation (Table 7) is positive. Since B-coefficient is a measure of the structural modification induced by solute-solvent interactions L-Arginine with negative dB/dT behaves as structure maker in Urea(aq) whereas L-Threonine with positive dB/dT behaves as structure breaker in Urea(aq) (Zhao., 2006).

A-coefficient (Table 7) represents the extent of solute-solute interactions (Waris et al., 2001).

Refractive index (n_D) measured experimentally can be related to the interactions in the solution. The values of n_D increase with the increase in concentration (Table 8) of amino acids and decrease with the increase of temperature. n_D data were used to calculate Molar Refractivity (R_D) (Table 9) using Lorentz-Lorenz equation (Zhao et al., 2011).

From the experimental and computed data for solutions of amino acids in Urea(aq) it can be generalized that when urea is dissolved in water fits into the water structure without significantly ordering or disordering it. The large attractive energy makes urea resemble both structurally and energetically water like structure. Two view points for protein denaturation are mentioned in the literature: (i) Urea acts on a protein indirectly by mutating the H-bond structure of water and thus disturbing the water mediated hydrophobic interactions. (ii) Urea co-operates with water in solvation of amino acid. Due to this weakening of hydrophobic interactions occur because urea is more effective than water in solvating hydrophobic residues as reported elsewhere already (Parmar et al., 2004).

When amino acid is introduced in solvent, hydration behaviour can be accounted to: (i) terminal group of zwitterions of amino acids (NH_3^+ and COO^-) are hydrated in electrostatic manner, hydration in backbone vary with the amino acid. (ii) Electrostatic influence of $NH_3^+ > COO^-$. (iii) Overlap of hydration cospheres of terminal (NH_3^+ and COO^-) groups and of adjacent groups resulting in volume change. The results can be explained that when amino acid is introduced in solvent the zwitterions are formed. Strong electrostatic forces between solvent molecules and zwitterions of amino acids produce greater cohesion in the solution. The structures of amino acids further influence the extent of interactions. Size of solute molecules can be related to larger B-coefficient values.

The formation of dipole-dipole or hydrogen bonding type of interactions between two similar or dissimilar components, formation of small entities due to breaking of self associations are few chemical phenomena occurring due to solute-solute and solute-solvent interactions which take place on mixing of the components (Korolev, 2008). This hypothesis stands proved from the experimental results, computation of derived parameters and the interpretation of data obtained for binary solutions.

Table1. Density of Amino Acids (L-Arginine, L-Threonine)+ Urea(aq) at 298K and 308K measured using precalibrated bicapillary pyknometer

Density[ρ(xkg m^{-3})]				
	298K		308K	
Conc. (mol Kg^{-1})	L-Arginine	L-Threonine	L-Arginine	L-Threonine
0.0000	996.9	996.9	994.3	994.3
0.1030	1002.6	1000.3	999.9	997.3
0.2060	1007.1	1006.3	1004.5	1002.8
0.3090	1012.0	1010.1	1009.4	1006.6
0.4119	1016.0	1014.3	1013.1	1009.7
0.5149	1020.4	1017.9	1017.6	1013.0
0.6179	1024.8	1021.4	1021.9	1016.2
0.7209	1028.8	-----	1025.9	-----
0.8239	1032.9	-----	1029.9	-----
0.9269	1036.7	-----	1033.8	-----
1.0298	1040.6	-----	1037.7	-----

Table 2. Viscosity of Amino Acids (L-Arginine, L-Threonine)+ Urea(aq) at 298K and 308K measured using precalibrated Ostwald's viscometer

Viscosity[η/(x10^{-3} Ns m^{-2})]				
	298K		308K	
Conc. (mol Kg^{-1})	L-Arginine	L-Threonine	L-Arginine	L-Threonine

0.0000	0.8799	0.8799	0.7150	0.7150
0.1030	0.9082	0.9391	0.7507	0.7594
0.2060	0.9543	0.9750	0.7903	0.7860
0.3090	1.0070	1.0025	0.8261	0.8055
0.4119	1.0811	1.0293	0.8858	0.8354
0.5149	1.1388	1.0728	0.9276	0.8662
0.6179	1.1772	1.1090	0.9580	0.8990
0.7209	1.2848	-----	1.0338	-----
0.8239	1.3798	-----	1.0896	-----
0.9269	1.4279	-----	1.1378	-----
1.0298	1.4892	-----	1.1948	-----

Table 3. Sound speed of Amino Acids (L-Arginine, L-Threonine)+ Urea(aq) at 298K and 308K measured using precalibrated ultrasonic interferometer

Sound Speed [u (x ms^{-1})]				
	298K		308K	
Conc. (mol Kg^{-1})	L-Arginine	L-Threonine	L-Arginine	L-Threonine
0.0000	1501.4	1501.4	1509.2	1509.2
0.1030	1510.0	1510.0	1528.4	1521.4
0.2060	1518.8	1514.4	1536.8	1529.8
0.3090	1523.8	1521.6	1540.8	1536.2
0.4119	1529.8	1528.6	1548.4	1544.4
0.5149	1537.4	1535.4	1555.2	1552.8
0.6179	1544.6	1543.2	1563.6	1562.2
0.7209	1547.8	-----	1566.2	-----
0.8239	1551.6	-----	1570.4	-----
0.9269	1556.8	-----	1576.2	-----
1.0298	1563.2	-----	1581.2	-----

Table 4. Apparent Molal Volume [ϕ_v] of Amino Acids (L-Arginine, L-Threonine)+ Urea(aq) at 298K and 308K

Apparent Molal Volume[ϕ_v (x 10^{-3} m^3 mol^{-1})]				
	298K		308K	
Conc. (mol Kg^{-1})	L-Arginine	L-Threonine	L-Arginine	L-Threonine
0.0000	-----	-----	-----	-----
0.1030	0.1185	0.0858	0.1194	0.0904
0.2060	0.1233	0.0729	0.1239	0.0773
0.3090	0.1234	0.0754	0.1240	0.0785
0.4119	0.1256	0.0756	0.1266	0.0809
0.5149	0.1258	0.0768	0.1266	0.0815
0.6179	0.1258	0.0776	0.1266	0.0822
0.7209	0.1261	-----	0.1269	-----
0.8239	0.1262	-----	0.1270	-----
0.9269	0.1264	-----	0.1271	-----
1.0298	0.1264	-----	0.1271	-----

Table 5. Hydration number [H_n] of Amino Acids (L-Arginine, L-Threonine)+ Urea(aq) at 298K and 308K				
Hydration Number [H_n(x10^{-3})]				
	298K		308K	
Conc. (mol Kg^{-1})	L-Arginine	L-Threonine	L-Arginine	L-Threonine
0.0000	-----	-----	-----	-----
0.1030	1.6967	1.4741	3.0441	1.8901
0.2060	1.6377	1.3138	2.2692	1.7509
0.3090	1.4582	1.3045	1.8303	1.5551
0.4119	1.3728	1.2962	1.6907	1.4894
0.5149	1.3652	1.2713	1.5956	1.4566
0.6179	1.3482	1.2701	1.5586	1.4465
0.7209	1.2609	-----	1.4292	-----
0.8239	1.2037	-----	1.3539	-----
0.9269	1.1738	-----	1.3135	-----
1.0298	1.1629	-----	1.2707	-----

Table 6. Viscous Relaxation Time [τ] of Amino Acids (L-Arginine, L-Threonine)+ Urea(aq) at 298K and 308K				
Viscous Relaxation Time [τ (x10^{-13}s)]				
	298K		308K	
Conc. (mol Kg^{-1})	L-Arginine	L-Threonine	L-Arginine	L-Threonine
0.0000	5.2206	5.2206	4.2097	4.2097
0.1030	5.2976	5.4898	4.2849	4.3862
0.2060	5.4771	5.6331	4.4415	4.4654
0.3090	5.7138	5.7155	4.5964	4.5210
0.4119	6.0626	5.7908	4.8621	4.6252
0.5149	6.2958	5.9611	5.0254	4.7283
0.6179	6.4198	6.0790	5.1125	4.8335
0.7209	6.9505	-----	5.4774	-----
0.8239	7.3987	-----	5.7200	-----
0.9269	7.5774	-----	5.9067	-----
1.0298	7.8083	-----	6.1401	-----

Table 7. Limiting Apparent Molal Volume (ϕ_v°), Limiting Apparent Molal Compressibility (ϕ_k°), Constant S_v* and S_k*, Falkenhagen Coefficient A, B-coefficient, Free energy of Activation of viscous flow per mole of solvent ($\Delta\mu_1^{\circ\#}$) and Free energy of Activation of viscous flow per mole of Solute ($\Delta\mu_2^{\circ\#}$) of Amino Acids (L-Arginine, L-Threonine)+ Urea(aq) at 298K and 308K

	L-Arg+Urea(aq)							
	ϕ_v°	S_v*	ϕ_k°	S_k*	A	B	$\Delta\mu_1^{\circ\#}$	$\Delta\mu_2^{\circ\#}$
	(x 10^{-3} m^3 mol^{-1})	(x$10^{-3}$$m^3$ $lt^{1/2}$ $mol^{-3/2}$)	(x10^{-10} m^2 N^{-1})	(x10^{-10} $N^{-1}m^{-1}$ mol^{-1})	($dm^{3/2}$ $m^{-1/2}$)	(dm^3 mol^{-1})	(x kJ mol^{-1})	(x kJ mol^{-1})
298K	0.1211	0.0064	-0.9651	0.3236	-0.2088	0.8777	9.14	143.55
308K	0.1220	0.0063	-1.3458	0.7303	-0.1078	0.7406	8.92	128.24

L-Thr+Urea(aq)								
298K	0.0799	-0.0085	-0.8009	0.1534	0.0662	0.3368	9.14	63.70
308K	0.0868	-0.0134	-0.9760	0.3852	0.0403	0.3581	8.92	69.25

Table 8. Refractive Index (n_D) of Amino Acids (L-Arginine, L-Threonine)+Urea(aq) at 298K and 308K using precalibrated Abbe's Refractometer

Refractive Index (n_D)				
	298K		308K	
Conc. (mol Kg^{-1})	L-Arginine	L-Threonine	L-Arginine	L-Threonine
0.0000	1.3405	1.3405	1.3398	1.3398
0.1030	1.3447	1.3415	1.3446	1.3410
0.2060	1.3489	1.3436	1.3487	1.3431
0.3090	1.3533	1.3455	1.3524	1.3448
0.4119	1.3543	1.3475	1.3537	1.3463
0.5149	1.3607	1.3490	1.3599	1.3480
0.6179	1.3617	1.3512	1.3607	1.3501
0.7209	1.3651	-----	1.3641	-----
0.8239	1.3661	-----	1.3654	-----
0.9269	1.3711	-----	1.3709	-----
1.0298	1.3724	-----	1.3714	-----

Table 9. Molar Refractivity (R_D) of Amino Acids (L-Arginine, L-Threonine)+ Urea(aq) at 298K and 308K

Molar Refractivity (R_D)				
	298K		308K	
Conc. (mol Kg^{-1})	L-Arginine	L-Threonine	L-Arginine	L-Threonine
0.0000	3.7915	3.7915	3.7942	3.7942
0.1030	3.8734	3.8281	3.8825	3.8345
0.2060	3.9596	3.8658	3.9679	3.8739
0.3090	4.0468	3.9095	4.0482	3.9158
0.4119	4.1027	3.9528	4.1080	3.9585
0.5149	4.2132	3.9930	4.2165	4.0018
0.6179	4.2670	4.0408	4.2684	4.0501
0.7209	4.3477	-----	4.3493	-----
0.8239	4.4025	-----	4.4077	-----
0.9269	4.5013	-----	4.5118	-----
1.0298	4.5597	-----	4.5615	-----

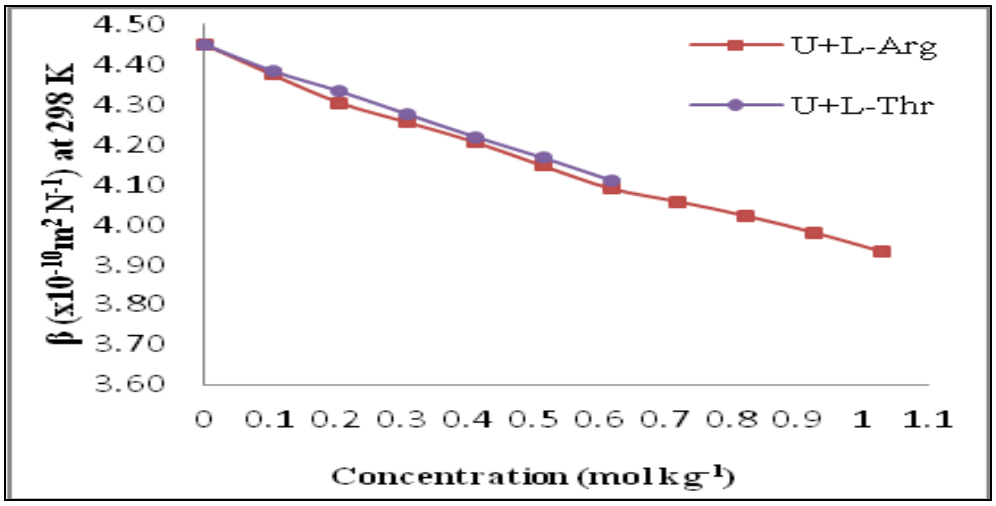

Fig. 1.Variation of Adiabatic Compressibility (β) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 298K

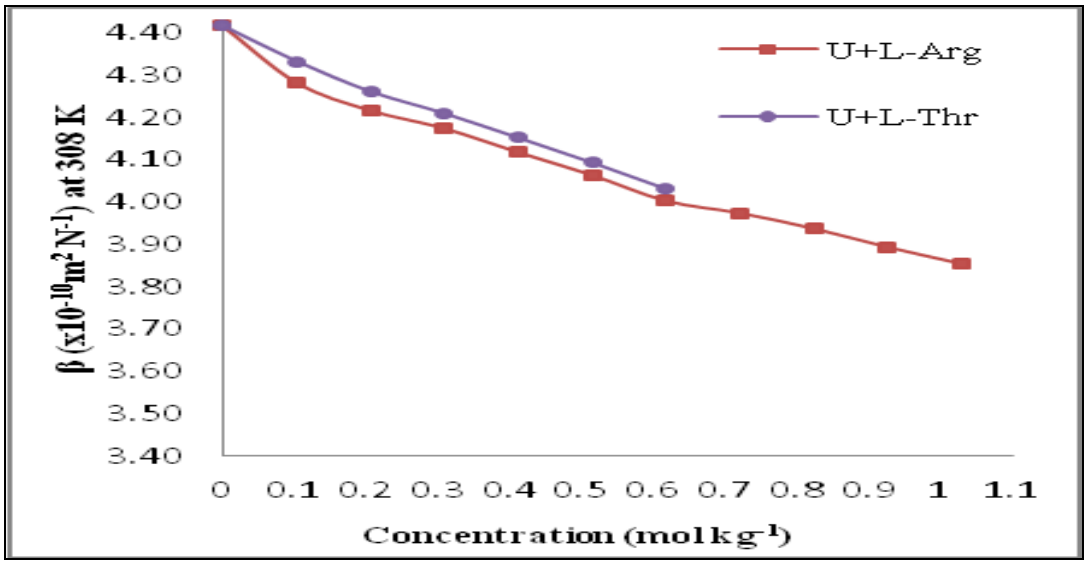

Fig. 2. Variation of Adiabatic Compressibility (β) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 308K

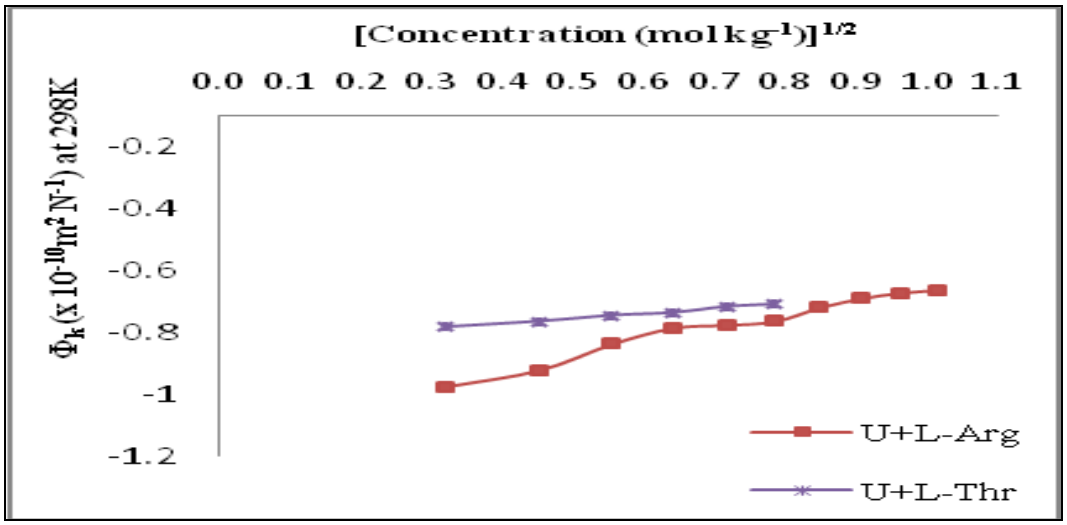

Fig. 3. Variation of Apparent Molal Compressibility (ϕ_k) with $m^{1/2}$ of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 298K

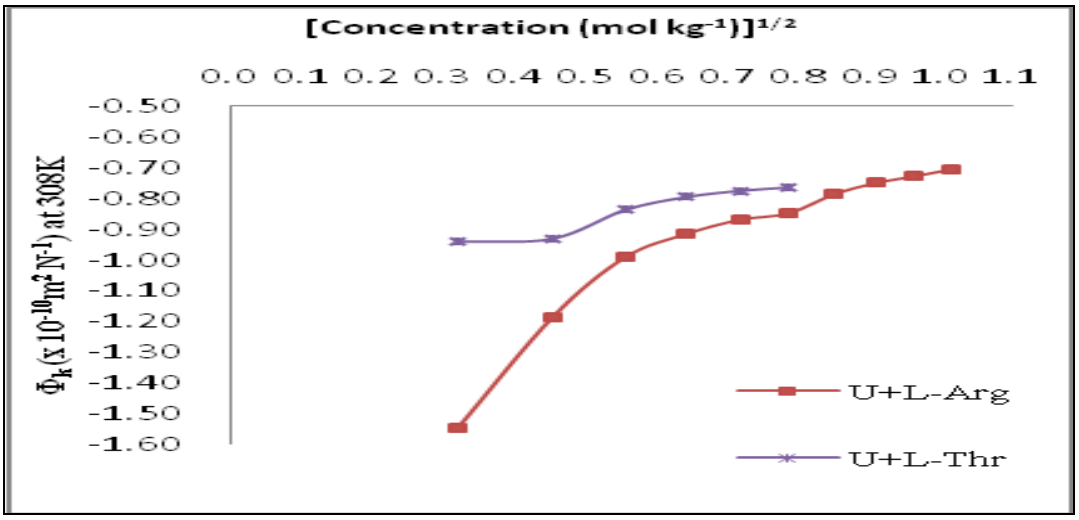

Fig. 4. Variation of Apparent Molal Compressibility (ϕ_k) with $m^{1/2}$ of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 308K

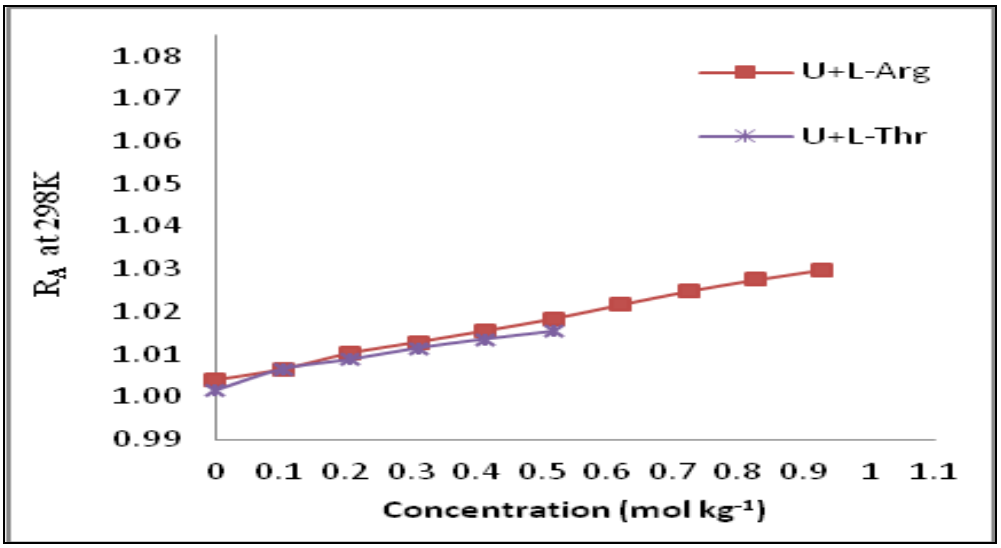

Fig. 5. Variation of Relative Association (R_A) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 298K

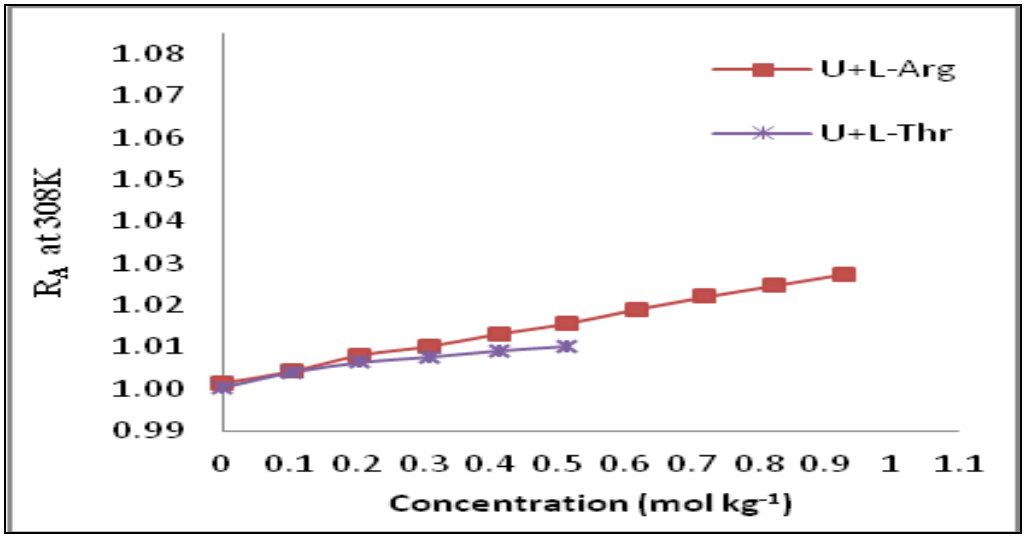

Fig. 6. Variation of Relative Association (R_A) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 308K

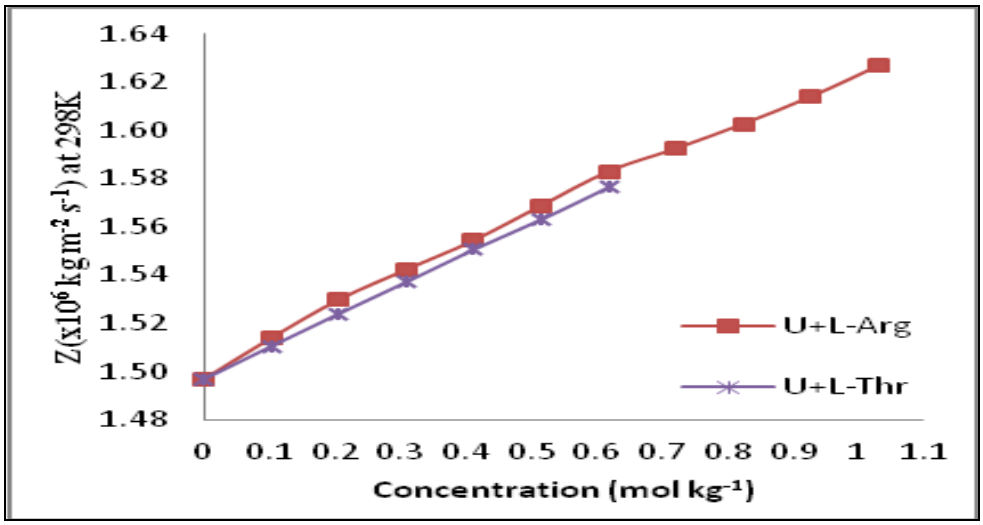

Fig. 7. Variation of Specific Acoustic Impedance (Z) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 298K

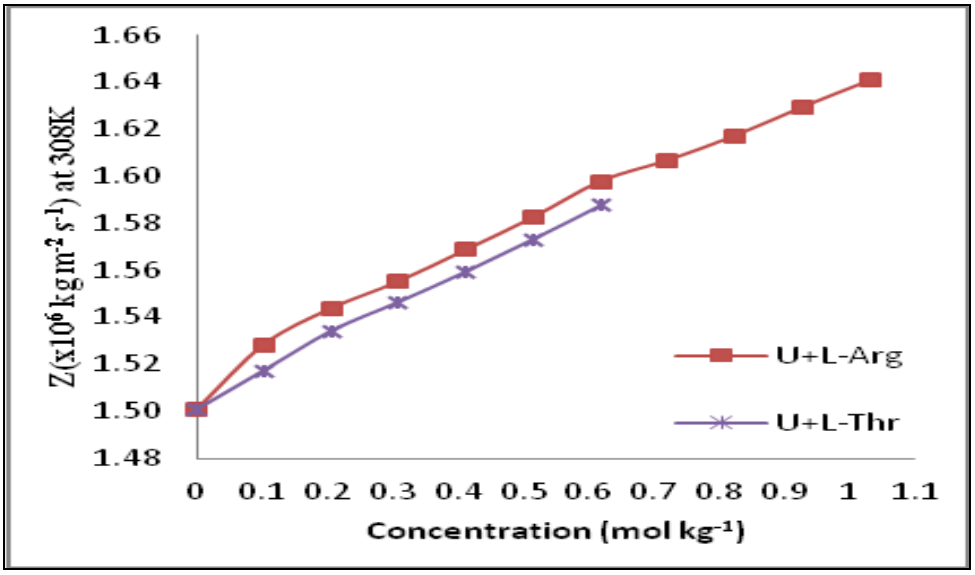

Fig. 8. Variation of Specific Acoustic Impedance (Z) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 308K

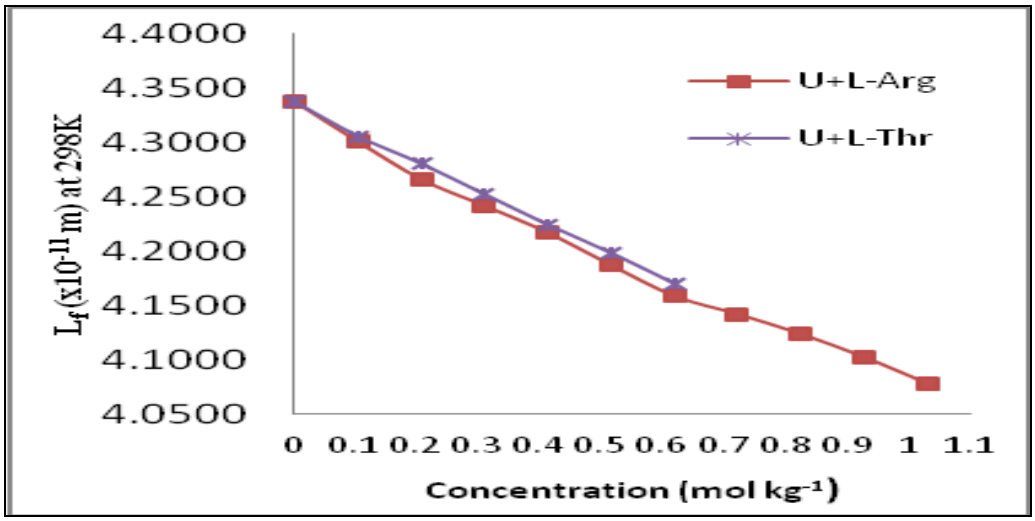

Fig. 9. Variation of Intermolecular free length (L_f) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 298K

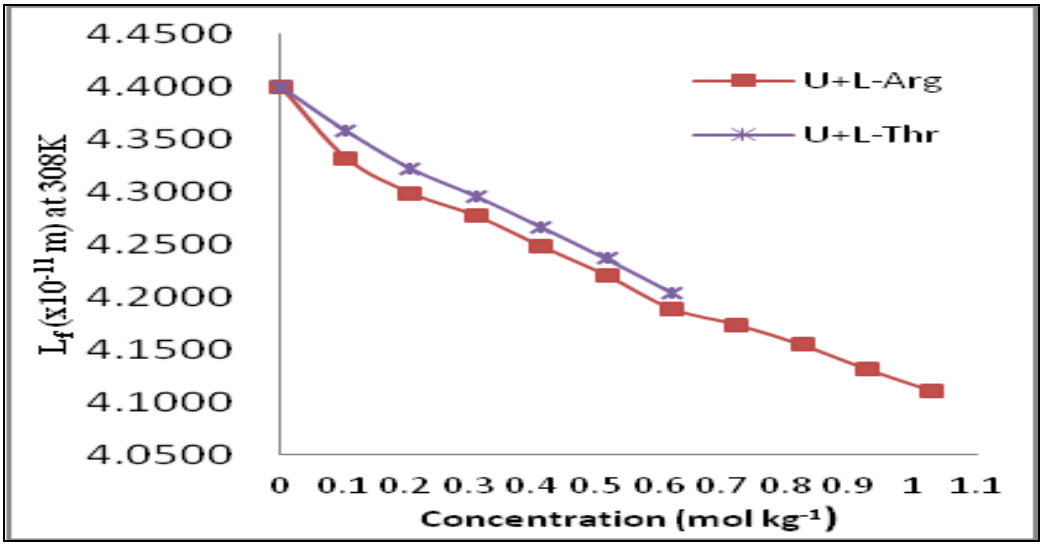

Fig.10. Variation of Intermolecular free length (L_f) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 308K

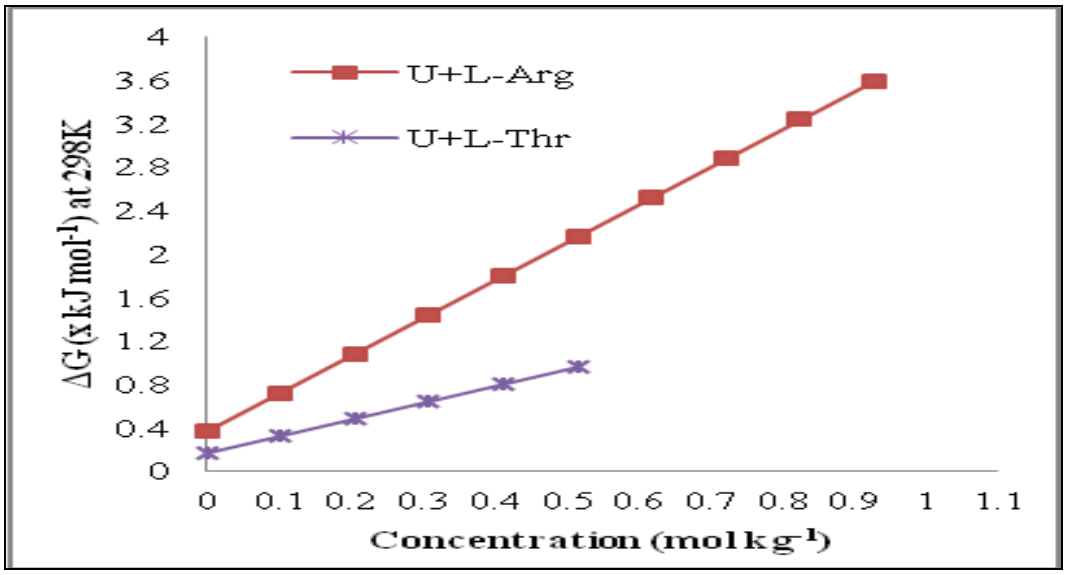

Fig.11. Variation of change in Gibb's free energy (ΔG) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 298K

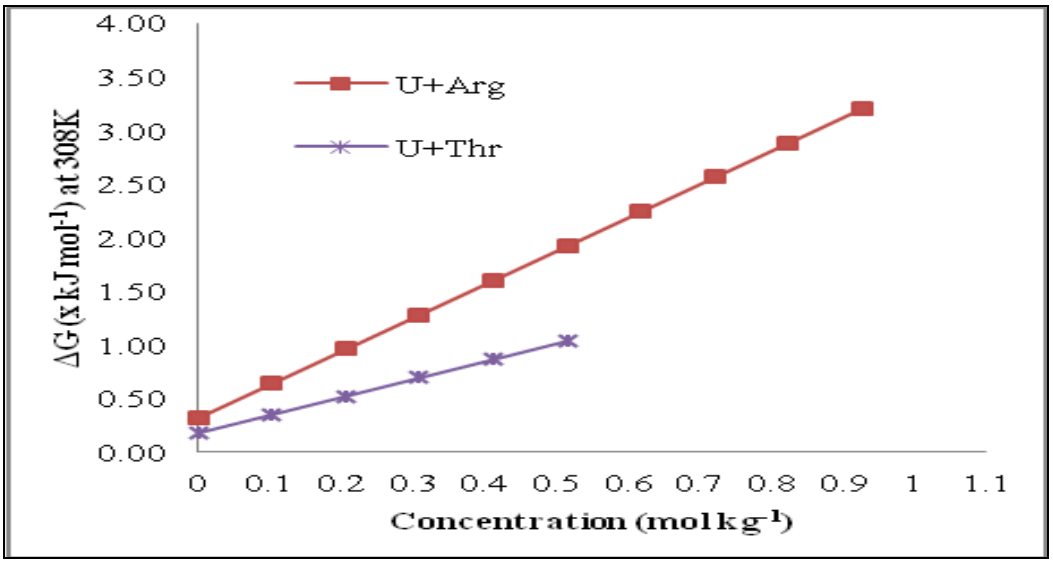

Fig.12. Variation of change in Gibb's free energy (ΔG) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq) at 308K

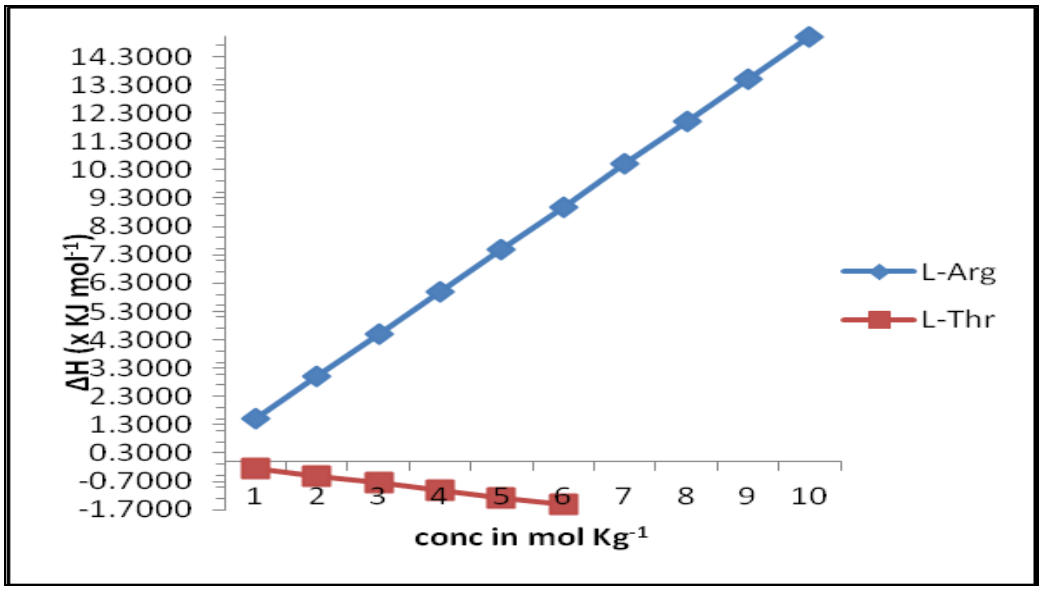

Fig.13. Variation of change in enthalpy (ΔH) (obtained from the intercept of the plot of ΔG vs T) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq)

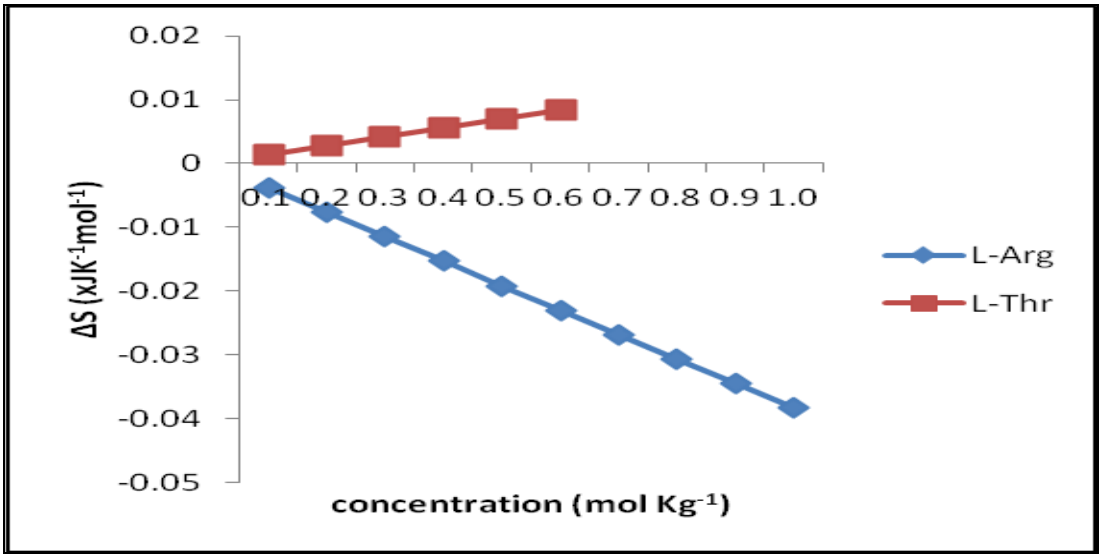

Fig.14. Variation of change in entropy (ΔS) (obtained from the slope of the plot of ΔG vs T) with m of Amino acids (L-Arginine, L-Threonine)+Urea(aq)

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