Study of Acoustic and Thermodynamic Parameters for Different Ratios of Aqueous Sodium Chloride and Potassium Chloride Solution At and About the Normal Human Body Temperature

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Abstract: Ultrasonic velocity, density and viscosity measurements have been determined for different ratios of aqueous sodium chloride and potassium chloride solution at and about normal body temperature. The ratio required for the homeostatic balance in the human body is analysed in terms of the thermodynamic parameters derived from the ultrasonic data.

Keywords: Ultrasonic velocity, thermodynamic parameters, homeostatic balance, mineral ratios

1. Introduction

Ultrasonic is a versatile non-destructive technique which finds extensive application in investigating various physiochemical parameters involving molecular interactions in liquid mixtures.

Recent studies **[1,2]** have also shown use of ultrasonic in engineering, agriculture and medicine. In engineering it is used to study the structure of materials. Ultrasonic pulses can speed up certain chemical reactions and act as a catalytic agent in wheat germination. The magnitude of ultrasonic velocity in human body fluids or organs is of vital importance for carrying out acoustical analysis of human system or organs.

Balance in all phase of life is critically important to maintain good health. This principle applies to mineral levels in the human body. Mineral ratios are often more important in nutritional deficiencies and excesses than mineral levels alone. It has been seen that mineral ratios represent homeostatic balance. They are indicative of disease trends. Ratios are also frequently predictive of future metabolic dysfunction or hidden metabolic dysfunctions. The basic mineral ratios that are important are;

(i)
$$\frac{Na}{R}$$
 ratio (ii) $\frac{Ca}{Mg}$ ratio (iii) $\frac{Na}{Mg}$ ratio (iv) $\frac{Ca}{R}$ ratio (v) $\frac{Zn}{Cu}$ ratio

Sodium to potassium ratio is referred to as the life death ratio. Sodium maintains normal distribution of water and the osmotic pressure in the various fluid components. Increased sodium levels are found to cause severe dehydration. Potassium influences the acid-base balance and osmotic pressure including water retention.

Sodium is normally extracellular while potassium is intracellular. If this ratio is imbalanced it indicates important physiological malfunction within the cells. An unbalanced Na/K ratio is associated with heart, kidney, liver and immune deficiency disease. The Na/K ratio which exhibits good health condition is about 2.5, which is obtained from hair analysis test. It has been observed that the abnormalities or a deficiency in the body is more evident in the hair analysis test compared to blood test. In blood test the same ratio (Na/K) known as validity ratio is obtained near about 28.5.

In this paper we have studied the thermodynamic parameters of importance for different sodium potassium ratio (obtained from hair analysis test) taking aqueous solution of NaCl and KCl at different temperatures about the body temperature (310 K).

2. Experimental Technique

The aqueous solution of various concentrations in mole fraction were prepared by taking analytical reagent grade and spectroscopic reagent grade chemicals with minimum assay of 99.9% and obtained from E.Merck Ltd (India).

The density, viscosity, and ultrasonic velocity were measured as a function of concentration of the solution at temperatures 298K, 308K, 310K, 313K and 318K.

Ultrasonic velocity measurements were made using an ultrasonic interferometer (Model M-84, supplied by M/S Mittal Enterprises, New Delhi), at 298K, 308K, 310K, 313K and 318K with the accuracy of ± 0.1 m·s-1. The measuring cell of interferometer is a specially designed double-walled vessel with provision for temperature constancy. An electronically operated digital constant temperature bath (Model SSI-03 Spl, supplied by M/S Mittal Enterprises, New Delhi), operating in the temperature range of -10° C to 85°C with an accuracy of $\pm 0.1^{\circ}$ C has been used to circulate water through the outer jacket of the double-walled measuring cell containing the experimental liquid.

The densities of the mixture were measured using a 10-ml specific gravity bottle by relative measurement method

International Symposium on Ultrasonics-2015, 22-24 January 2015 Department of Physics, Rashtrasant Tukdoji Maharaj Nagpur University, Nagpur, Maharashtra, India Licensed Under Creative Commons Attribution CC BY with an accuracy of ± 0.01 kg·m-3. The specific gravity bottle with the experimental mixture was immersed in the temperature-controlled water bath. The weight of the sample was measured using an electronic digital balance with an accuracy of ± 0.1 mg (Model: SHIMADZU AX-200, Kyoto, Japan).

An Oswald viscometer (10 ml) with an accuracy of \pm 0.001 Ns·m-2 was used for the viscosity measurement. The flow time was determined using a digital racer stopwatch with an accuracy of \pm 0.1s.

3. Theory

1. Adiabatic Compressibility:

The ultrasonic velocity in a liquid medium, in terms of Bulk modulus (B) and density of the medium is given by the Newton-Laplace equation [3].

$$U = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{1}{\rho \cdot \beta}}$$

Or,
$$\beta = \frac{1}{\rho \cdot v^2} \dots \dots (N^{-1} \cdot m^2) \dots \dots \dots \dots \dots (1)$$

2. Intermolecular Free Length:

Intermolecular free length (L_f) , is calculated using the standard expression [4]

$$L_f = K_T \cdot \beta^{1/2} \dots \dots \dots (m) \dots \dots (2)$$

Where, ' K_T ' {=(93.875 + 0.375.T) x 10⁻⁸} is Jacobson's temperature dependent constant and ' β ' is the adiabatic compressibility.

3. Free Volume:

Suryanarayana et al [5,6] obtained a relation for free volume in terms of ultrasonic velocity (U) and the viscosity of the liquid (η) as,

$$W_f = \left(\frac{M_{eff}U}{K\eta}\right)^{3/2} \dots \dots (m^3.mol^{-1})\dots\dots (3)$$

Where ' M_{eff} ' is the effective mass of the mixture, 'K' is a dimensionless constant independent of temperature and liquid. Its value is 4.281 x 10⁹.

4. Internal Pressure:

Internal pressure can be calculated by using the relation [7,8]



Where, 'b' stands for the cubic packing factor, which is assumed to be '2' for all liquids and solutions. 'K' is a dimensionless constant independent of temperature and nature of liquids. Its value is 4.281x109, R is the gas constant, T is the absolute temperature, η is the viscosity, U is the ultrasonic velocity, ρ is the density and M is the effective molecular weight.

5. Viscous Relaxation Time (**7**):

The relaxation time can be calculated using the relation **[9]**,

$$τ = \frac{4}{3}$$
. (β.η)(s)(5)

Where, ' β ' is the adiabatic compressibility and ' η ' is the viscosity of the mixture.

6. Acoustic Impedance (Z):

The specific acoustic impendence is given by [10]

7. Gibb's Free Energy:

The variation of ' $\mathbf{\tau}$ ' with temperature can be expressed in the form of Eyring salt process theory [9].

$$\frac{4}{\tau} = \frac{KT}{h} \exp\left(\frac{-\Delta G}{KT}\right)$$

The above equation can be rearranged as

$$\Delta \mathbf{G} = 2.30.\mathrm{KT}\log\left(\frac{\mathrm{KT}\tau}{\mathrm{h}}\right) \dots (\mathrm{k.J.mol}^{-1}) \dots (7)$$

Where, ' τ ' is the viscous relaxation time, 'T' is the absolute temperature, 'K' is the Boltzmann's constant and 'h' is the Plank's constant.

8. Molar Volume:

Molar volume can be calculated by using the relation [11]

Where, M_{eff} is the effective molecular weight and ρ is the density of the solution.

9. Available Volume:

Available volume is the direct measure of compactness and strength of binding between the molecules of liquid or liquid mixture. Schaffs et al [12] shown that the available volume can be obtained by the relation.

Another parameter which can be calculate from ultrasonic velocity is the available volume and is given by

$$\mathbf{V}_{\mathbf{a}} = \mathbf{V}_{\mathbf{m}^{\mathbf{r}}} \left(\mathbf{1} - \frac{\boldsymbol{u}}{\boldsymbol{u}_{\mathbf{n}}} \right) \dots \left(\mathbf{m}^{3} \operatorname{mol}^{-1} \right) \dots \left(\mathbf{9} \right)$$

Where, $V_m = M/\rho$, is the molar volume, U = velocity, and $U_{\infty} =$ Schaff's limiting value taken as 1600 m/s for liquids.

10. Rao's Constant:

Rao's constant is also known as molar sound velocity and it is an additive property. It has been found to be invariant with temperature and pressure for un-associated organic and inorganic liquid. R can be evaluated by an equation given by Bagchi et al [13]

$$\boldsymbol{R} = \begin{pmatrix} \mathbf{M}_{\text{eff}} \\ \boldsymbol{\rho} \end{pmatrix}, \boldsymbol{U}^{\frac{1}{3}} = \boldsymbol{V}_{\boldsymbol{m}}, \boldsymbol{U}^{\frac{1}{3}} \qquad \dots \qquad (\text{m}^{3}.\text{mol})^{1}$$

11. Wada's Constant:

Molar compressibility is also known as Wada's constant, which is dependent on adiabatic compressibility and density, is given by the relation **[14]**

$$\mathbf{W} = \left(\frac{\mathbf{M}_{\text{eff}}}{\boldsymbol{\beta}}\right) \cdot \boldsymbol{\beta}^{-\frac{1}{7}} = \mathbf{V}_{\text{m}} \cdot \boldsymbol{\beta}^{-\frac{1}{7}} \dots (\text{m}^{3}.\text{mol}^{-1}) \dots (11)$$

12. Surface Tension:

Surface tension can be calculated by using the relation [15]

4. Result and Discussion

We have studied the thermodynamic parameters for different ratios of Na to K between 0.5:1 to 7:1 at temperatures 298K, 308K, 310K, 313K and 318K. The experimental values of density, viscosity and velocity are presented in table-1. Calculated values of acoustic and thermodynamic parameters are presented in table-2, to table-5. Variations of some parameters with mole fraction of NaCl are shown in fig.1 to fig.-8.

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Table 1: Values of Density (ρ), Viscosity (η) and velocity (V) of mixture at 298k, 308k, 310k, 313k and 318k

Mole f	raction	Na/K		Den		Viscosity	(η) (x10	⁻³ N.s.m ⁻²))		Velo	ocity (U) (m.s	5 ⁻²)				
NaCl	KCl		298 K	308K	310 K	313 K	318 K	298K	308K	310K	313K	318 K	298 K	308K	310 K	313 K	318 K
0.0031	0.0048	1:2	1035.25	1030.27	1027.68	1024.68	1020.76	0.895	0.723	0.692	0.656	0.591	1549.50	1568.30	1572.80	1575.87	1583.30
0.0121	0.0048	2:1	1039.91	1033.98	1030.47	1027.46	1023.54	0.915	0.736	0.705	0.671	0.600	1560.90	1577.40	1580.80	1585.30	1591.40
0.0151	0.0047	2.5:1	1043.64	1038.63	1036.96	1033.02	1031.87	0.929	0.748	0.718	0.682	0.613	1567.67	1584.40	1587.90	1591.50	1599.56
0.0181	0.0047	3:1	1048.30	1043.27	1040.68	1038.66	1037.42	0.955	0.762	0.722	0.694	0.625	1583.67	1593.00	1597.00	1600.00	1608.23
0.0210	0.0047	3.5:1	1054.82	1048.92	1045.32	1042.30	1039.20	0.978	0.780	0.730	0.702	0.637	1594.40	1605.10	1608.60	1611.40	1616.10
0.0240	0.0047	4:1	1065.07	1059.14	1055.53	1052.50	1050.38	1.011	0.801	0.746	0.714	0.656	1609.34	1616.00	1619.90	1622.80	1627.67
0.0269	0.0047	4.5:1	1072.06	1063.31	1061.10	1058.06	1055.13	1.032	0.821	0.769	0.731	0.671	1618.34	1628.85	1632.60	1633.90	1638.98
0.0412	0.0046	7:1	1102.34	1096.23	1093.25	1090.53	1087.39	1.114	0.890	0.845	0.780	0.725	1654.90	1665.90	1668.10	1671.80	1674.30

Table 2: Values of adiabatic compressibility (β), Viscous relaxation time (τ) and Free length (L_f) of mixture at 298k, 308k, 310k, 313k and318k

Mole fraction		Na/K	Adiabatic compressibility (β) (x10 ⁻¹⁰ N ⁻¹ .m ²)						Viso	cous rel. tin (x 10 ⁻¹² s	me (τ))		Free length (L _t) (10 ⁻¹⁰ m)					
NaCl	KCl		298 K	308K	310 K	313 K	318 K	298 K	308K	310 K	313 K	318 K	298 K	308K	310 K	313 K	318 K	
0.0031	0.0048	1:2	4.0232	3.9463	3.9336	3.9298	3.9080	0.480	0.380	0.363	0.344	0.308	0.3971	0.4015	0.4012	0.4016	0.4015	
0.0121	0.0048	2:1	3.9469	3.8869	3.8834	3.8727	3.8578	0.482	0.381	0.365	0.346	0.309	0.3934	0.3985	0.3987	0.3986	0.3989	
0.0151	0.0047	2.5:1	3.8989	3.8354	3.8246	3.8219	3.7877	0.483	0.383	0.366	0.348	0.310	0.3910	0.3958	0.3956	0.3960	0.3953	
0.0181	0.0047	3:1	3.8035	3.7772	3.7677	3.7609	3.7269	0.484	0.384	0.363	0.348	0.311	0.3862	0.3928	0.3927	0.3928	0.3921	
0.0210	0.0047	3.5:1	3.7293	3.7005	3.6970	3.6949	3.6844	0.486	0.385	0.360	0.346	0.313	0.3824	0.3888	0.3890	0.3894	0.3898	
0.0240	0.0047	4:1	3.6252	3.6155	3.6104	3.6078	3.5935	0.489	0.386	0.359	0.343	0.314	0.3770	0.3843	0.3844	0.3848	0.3850	
0.0269	0.0047	4.5:1	3.5616	3.5447	3.5358	3.5403	3.5281	0.490	0.388	0.363	0.345	0.316	0.3737	0.3805	0.3804	0.3811	0.3815	
0.0412	0.0046	7:1	3.3124	3.2870	3.2873	3.2809	3.2806	0.492	0.390	0.370	0.341	0.317	0.3604	0.3664	0.3668	0.3669	0.3679	

Table 3: Values of acoustic impedance (Z), Gibb's free energy (ΔG), and internal pressure (π_i) of mixture at 298k, 308k, 310k, 313k and 318k.

Mole fraction		N (Acousti (x 10	c impeda ⁶ Kg.m².8	nce (Z) Sec ⁻¹)			Gibb': (x	s free energ 10 ⁻²⁰ k.J.n	gy (∆G) nol⁻¹)		Internal pressure(π _i) (x 10 ⁶ N.m ⁻²)					
NaCl	KCl	K	298 K	308K	310 K	313 K	318 K	298 K	308K	310 K	313 K	318 K	298 K	308K	310 K	313 K	318 K	
0.0031	0.0048	1:2	1.604	1.616	1.616	1.615	1.616	0.4494	0.3796	0.3647	0.3488	0.3131	2665.5	2453.3	2408.2	2360.5	2265.2	
0.0121	0.0048	2:1	1.623	1.631	1.629	1.629	1.629	0.4506	0.3807	0.3671	0.3523	0.3141	2632.5	2418.2	2374.1	2330.7	2229.2	
0.0151	0.0047	2.5:	1.636	1.646	1.647	1.644	1.651	0.4518	0.3819	0.3684	0.3536	0.3154	2633.5	2421.7	2382.8	2336.2	2242.9	
0.0181	0.0047	3:1	1.660	1.662	1.662	1.662	1.668	0.4530	0.3833	0.3644	0.3542	0.3168	2645.0	2427.0	2370.9	2341.7	2250.2	
0.0210	0.0047	3.5:	1.682	1.684	1.682	1.680	1.679	0.4547	0.3845	0.3610	0.3515	0.3202	2659.4	2437.4	2365.2	2335.3	2252.4	
0.0240	0.0047	4:1	1.714	1.712	1.710	1.708	1.710	0.4567	0.3859	0.3601	0.3485	0.3221	2689.4	2459.9	2381.1	2345.4	2277.5	
0.0269	0.0047	4.5:	1.735	1.732	1.732	1.729	1.729	0.4579	0.3880	0.3642	0.3505	0.3240	2702.3	2469.6	2399.5	2356.7	2286.2	
0.0412	0.0046	7:1	1.824	1.826	1.824	1.823	1.821	0.4595	0.3902	0.3733	0.3557	0.3260	2733.8	2507.9	2453.5	2373.4	2318.6	

Table 4: Values of adiabatic Free volume (V_f), Available volume (V_a), and Molar Volume (V_m) of mixture at 298k, 308k,
310k, 313k and 318k.

Mole fi	raction	Na/	Free (x 10-	volume ⁷ m ³ .mo	(V.) 01 ⁻¹)			Availab (m ³ .mol	le volume ⁻¹)	(<u>V</u> a)			Molar Volume (Vm) (m ³ .mol ⁻¹)					
NaCl	KCl	ĸ	298	308	310	313	318	298 K	308K	310 K	313 K	318 K	298 K	308K	310 K	313 K	318 K	
0.003	0.004	1:2	0.20	0.28	0.30	0.33	0.39	0.0005	0.0003	0.0003	0.0002	0.0001	0.0177	0.0178	0.0179	0.0179	0.0180	
0.012	0.004	2:1	0.20	0.28	0.30	0.33	0.39	0.0004	0.0002	0.0002	0.0001	0.0001	0.0180	0.0181	0.0182	0.0182	0.0183	
0.015	0.004	2.5:1	0.20	0.28	0.30	0.33	0.39	0.0003	0.0001	0.0001	0.0001	0.0000	0.0181	0.0181	0.0182	0.0182	0.0183	
0.018	0.004	3:1	0.20	0.28	0.30	0.32	0.38	0.0001	0.0000	0.0000	0.0000	-	0.0181	0.0182	0.0182	0.0183	0.0183	
0.021	0.004	3.5:1	0.19	0.27	0.30	0.32	0.38	0.0000	-	-	-	-	0.0181	0.0182	0.0183	0.0183	0.0184	
0.024	0.004	4:1	0.19	0.27	0.30	0.32	0.37	-	-	-	-	-	0.0180	0.0181	0.0182	0.0182	0.0183	
0.026	0.004	4.5:1	0.18	0.26	0.29	0.32	0.36	-	-	-	-	-	0.0180	0.0182	0.0182	0.0183	0.0183	
0.041	0.004	7:1	0.18	0.25	0.27	0.31	0.35	-	-	-	-	-	0.0180	0.0181	0.0182	0.0182	0.0183	

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Table 5: Values of Rao's Constant (R), Wada Constant (W) and Surface tension (S) of mixture at 298k, 308k, 310k. 313k and 318k

Mo fra on	Mole fracti on		Ra (m	o's (³/mo	Cons de)(r	tant n/s) ¹	(R)	W W (m	ada) ³ /mo	Cor ole)	istan	t (s	Surface tension (S) (N.m ⁻¹)							
N a C l	K C l	K	2 9 8 K	3 0 8 K	3 1 0 K	3 1 3 K	3 1 8 K	2 9 8 K	3 0 8 K	3 1 0 K	3 1 3 K	318 K	2 9 8 K	3 0 8 K	3 1 0 K	3 1 3 K	3 1 8 K			
0 0 0 3 1	0 0 0 4 8	1 : 2	0 2 0 5 8	0 2 0 7 6	0 2 0 8 3	0 2 0 9 1	0 2 1 0 2	0 0 1 4 6	0 0 1 4 7	0 0 1 4 7	0 0 1 4 8	0.01 48	3 9 7 8 1	4 0 3 1 2	4 0 3 8 4	4 0 3 8 4	4 0 5 1 4			
0 0 1 2 1	0 0 0 4 8	2 : 1	0 2 0 9 4	0 2 1 1 4	0 2 1 2 2 2	0 2 1 3 1	0 2 1 4 2	0 0 1 4 8	0 0 1 5 0	0 0 1 5 0	0 0 1 5 1	0.01 51	4 0 4 0 2	4 0 8 1 0	4 0 8 0 3	4 0 8 5 8	4 0 9 3 7			
0 0 1 5 1	0 0 0 4 7	2 5 : 1	0 2 1 0 3	0 2 1 2 1 2 1	0 2 1 2 6	0 2 1 3 5	0 2 1 4 1	0 0 1 4 9	0 0 1 5 0	0 0 1 5 0	0 0 1 5 1	0.01 51	4 0 8 1 1	4 1 2 6 6	4 1 3 3 7	4 1 3 2 0	4 1 5 8 8			
0 0 1 8 1	0 0 0 4 7	3 : 1	0 2 1 1 4	0 2 1 2 9	0 2 1 3 6	0 2 1 4 1	0 2 1 4 7	0 0 1 5 0	0 0 1 5 1	0 0 1 5 1	0 0 1 5 1	0.01 52	4 1 6 2 2	4 1 7 8 9	4 1 8 4 2	4 1 8 7 9	4 2 1 5 2			
0 0 2 1 0	0 0 0 4 7	3 5 : 1	0 2 1 1 9	0 2 1 3 6	0 2 1 4 5	0 2 1 5 2	0 2 1 6 0	0 0 1 5 0	0 0 1 5 1	0 0 1 5 2	0 0 1 5 2	0.01 53	4 2 3 0 7	4 2 4 9 5	4 2 4 8 8	4 2 4 7 5	4 2 5 3 5			
0 0 2 4 0	0 0 0 4 7	4 : 1	0 2 1 1 8	0 2 1 3 3	0 2 1 4 2	0 2 1 4 9	0 2 1 5 6	0 0 1 5 0	0 0 1 5 1	0 0 1 5 2	0 0 1 5 2	0.01 53	4 3 3 2 0	4 3 3 4 7	4 3 5 5	4 3 4 7	4 3 4 5 5			
0 0 2 6 9	0 0 0 4 7	4 .5 : 1	0 2 1 2 1 2 1	0 2 1 4 3	0 2 1 4 9	0 2 1 5 6	0 2 1 6 4	0 0 1 5 1	0 0 1 5 2	0 0 1 5 2	0 0 1 5 3	0.01 53	4 3 9 7 1	4 4 0 3 7	4 4 0 9 8	4 4 0 2 4	4 4 1 0 7			
0 0 4 1 2	0 0 0 4 6	7 : 1	0 2 1 4 0	0 2 1 5 6	0 2 1 6 3	0 2 1 7 0	0 2 1 7 7	0 0 1 5 2	0 0 1 5 3	0 0 1 5 4	0 0 1 5 4	0.01 55	4 6 7 5 3	4 6 9 5 9	4 6 9 2 4	4 6 9 6 3	4 6 9 3 3			

Density increases as the ratio Na: K increases. This is because sodium ions are largely hydrated and hence are less mobile than potassium ions. As temperature increases the mobility of the ions increase, hence density decreases. Viscosity changes in the same way as density.

Ultrasonic velocity increases and adiabatic compressibility decreases as temperature increases and also with the increase in ratio of sodium to potassium. This is an indication that, the intermolecular force increases in both the cases. It is chiefly the compressibility that decreases due to structural changes of molecules in the mixture leading to an increase in ultrasonic velocity. Change in compressibility indicates that, in all the cases free length should decrease. However, free length decreases when Na/K ratio increases but increases with temperature and becomes constant for definite sodium to potassium ratio.





Figure 2: Variation of "β" with mole fraction of NaCl

Decrease in free length indicates a structure promoting behavior (greater association of the molecules). The increased cohesion between the molecules may be due to ionic hydration.

NaCl and KCl are strong electrolytes, which form Na^{+,} K⁺ and Cl⁻ in aqueous solution. Water molecules are attached to the ions strongly by electro-static forces the negative side of the water molecules remaining closely associated with the positive ions.



Figure 3: Reaction of Na with water

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When temperature increases the free length increases initially as the molecules gain thermal energy. However the strong electrostatic forces (due to more number of sodium ions being formed) pre vents a rapid increase in free length and free length becomes practically constant.



Figure 4: Variation of "L_F" with mole fraction of NaCl



Figure 5: Variation of "V_f" with mole fraction of NaCl

Relaxation time is the time taken for the excitation energy to appear as translational energy. It depends on temperature and impurities and is given by $\tau = \frac{1}{2} \beta \eta$. For a fixed temperature relaxation time remains practically constant as the ratio of Na/K increases. However, when the temperature changes, the fall in relaxation time is more from 298K to 308K and then becomes less. This is because the strong electrostatic force puts a restriction on the energy conversion and hence, change in relaxation time becomes slower.



Figure 6: Variation of " π_i " with mole fraction of NaCl



Acoustic impedance is the ratio of effective sound pressure at a point to the effective particle velocity at that point. Acoustic impedance remains practically constant as temperature increase for a particular ratio of sodium to potassium. This is due to the fact that cohesive force practically remains constant for a fixed ratio. However when Na/K ratio increases, temperature remaining constant, the cohesion force increase, hence acoustic impedance increases.

Increase in Gibbs' free energy suggests closer approach of molecules in the mixture and vice versa. In our case Gibbs' free energy decreases as temperature increase for a particular ratio of Na/K and increases very slowly as Na/K ratio increases for a particular temperature. At human body temperature (\sim 310K), Gibbs' free energy becomes minimum when the Na/K ratio is 4:1 which is also seen at temperature 313K. This minimum value of Gibbs' free energy indicates a good flow of the mixture.





Figure 8: Variation of " Δ G" with mole fraction of NaCl



Internal pressure decreases as temperature increases which is obvious as the cohesion force decreases due to the increase in thermal energy. Internal pressure increases mostly when the ratio of Na/K increases. At temperatures 298K, 308K, 313K and 318K internal pressure is minimum for the ratio 2:1 but minimum for the ratio 3.5:1 at body temperature 310K. We have seen that for good health condition the ratio varies between, 2:1 to 4:1. Minima condition in internal pressure shows decline in cohesive force which is also observed while studying Gibbs' free energy.

Free volume is the average volume in which the center of a molecule can move due to the repulsion of surrounding molecules. The effective free volume sometimes changes due to the transmission of collision effect through the molecules. This is why it increases as the temperature increases. Free volume appears to be maximum when internal pressure is minimum.

Molar volume $V_{f} = \frac{M_{eff}}{M_{eff}}$ should increases as thermal

energy facilitates increase in molecular separation. However the change is very slow as the effect due to thermal energy is restricted by the strong electrostatic force between the molecules. However molar volume shows a maxima for the Na/K ratio 3.5:1 at all temperatures.

Available volume is a direct measure of the compactness and strength of bonding between the molecules of the liquid mixture. Since ultrasonic velocity increases as temperature increases, available volume decreases indicating compactness of the molecules in the mixture.

The increasing trends of Rao's and Wada's constant with the increase of Na/K ratio and increase of temperature suggest the availability of more number of components in a given region indicating close packing of the medium. Rao's constant shows a slight fall in value for the ratio 4:1 at all temperatures.

Surface tension increases as temperature increases but slowly and also as the Na/K ratio increases indicating increase in molecular association. When ratio increases more Na⁺ ions are available in a region as they are less mobile than K^+ ions and Na^+ ions are also more hydrated.

5. Conclusion

The results of the present study signify that the ultrasonic velocity and other derived parameters depend on the mineral ratio (in this case Na/K ratio) as well as temperature. Temperatures are chosen about the body temperature. Certain parameters show changes within healthy ratio limit that is 2:1 to 4:1 and near the body temperature.

However in addition to Na/K ratio, one must consider other important ratios like Ca/Mg, Na/Mg, Ca/K, Zn/Cu for homeostatic balance. Ultrasonic study for the ratios obtained from hair analysis test and blood test at different temperatures and frequencies are in progress.

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