Acoustical behaviour of Sodium Dodecyl Sulphate in aqueous solution of filler sodium chloride at different temperatures

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Abstract: Ultrasonic velocity, density and viscosity of sodium chloride in aqueous sodium dodecyl sulphate (10 mm) solution at 298 ° K, 308 ° K, 318 ° K and 328 ° K have been measured. Using these experimental values, acoustical parameters such as adiabatic compressibility (β), intermolecular freelength (L_f), specific acoustic impedance (z), relaxation time (τ), relative association (R_A), absorption coefficient (α/f^2), acoustic attenuation and Lennard Jonne's potential were calculated. These parameters are extensively used to illustrate the nature of interactions between component molecules. Various molecular informations and structural variations of sodium chloride solution with the anionic surfactant sodium dodecyl sulphate have been analyzed on the basis of the changes in the above parameters with concentration and temperatures.

Keywords : Sodium dodecyl sulphate, acoustic impedance, freelength, relaxation time, adiabatic compressibility, velocity.

1. Introduction

Recent developments have found use of ultrasonic energy in medicine, engineering and agriculture [1-3]. A number of workers have reported the ultrasonic studies on different types of soaps and detergents [4-8]. Sodium salt is important to humanity as well as to plants. The ultrasonic behaviour of pure aqueous NaCl solutions is studied by M.K. Praharaj et al [9]. Literature survey reveals that thermo acoustic parameters of SDS with polyvinyl alcohol as medium were done by S.Ravichandran et al [10]. But this is the first attempt made to study the acoustical behaviour of sodium chloride solution at different concentrations with 10 mm sodium dodecyl sulphate.

2. Experimental Details

Solutions of sodium chloride of various concentration from (2 mm to 14 mm) are prepared in aqueous sodium dodecyl sulphate solution with fixed concentration of 10 mm (cmc value of SDS as reported by the previous workers [11] and present authors in earlier paper [12]).

2.1 Velocity measurement:

The velocities of ultrasonic wave in the above solution have been measured using ultrasonic interferometer supplied by Mittal Enterprises, New Delhi. The measuring cell of interferometer is a specially designed double walled vessel with the provision for temperature constancy. An electronically operated digital constant temperature bath supplied by Raaga industries, Chennai, operating in the temperature range 10°C to 90°C with an accuracy of $\pm$ 0.1 C has been used to circulate water through the outer jacket of the double walled measuring cell containing the experimental liquid.

2.2 Density measurement:

The densities of solutions are measured using a 10 ml specific gravity bottle. The specific gravity bottle with the experimental liquid is immersed in a temperature controlled water bath. The density was measured using the formula,

$\rho_2 = (m_2/m_1) * \rho_1$

where, m_1 = mass of distilled water, m_2 = mass of experimental liquid, ρ_1 = density of water, ρ_1 = density of experimental liquid.

2.3 Viscosity measurement:

The viscosities of solution are measured using an Ostwald's viscometer. The Ostwald's viscometer with the experimental liquid is immersed in a temperature controlled water bath. The time of flow was measured using a racer stop watch with an accuracy of 0.1 sec. The viscosity was determined using the relation,

$\eta_2 = \eta_1(t_2/t_1)*(\rho_2/\rho_1)$

where, η_1 = viscosity of water, η_2 = viscosity of experimental liquid, ρ_1 = density of water, ρ_2 = density of experimental liquid, t_1 = time of flow of water, t_2 = time of flow of experimental liquid.

3. Theoretical formulations

The following acoustical parameters were calculated from Jacobson's relation [13-15] using the velocity, density and viscosity values.

(i)   Adiabatic compressibility $\beta = (1/U^2\rho)$ $Kg^{-1}ms^2$ --------(1)
(ii) Intermolecular free length $L_f = (K * \beta^{1/2})$ m   --------(2)
(iii) Specific acoustic impedance $z = U * \rho$ $Kgm^{-2}s^{-1}$ --------(3)
(iv) Relaxation time $\tau = (4/3) * \beta * \eta$ sec   --------(4)
(v)   Relative association $R_A = (\rho/\rho_0) * (U_0/U)$ --------(5)
(vi) Absorption coefficient $\alpha/f^2 = (8*\pi^2*\eta)/(3*\rho*U^2)$ $m^{-1}s^2$ --------(6)
(vii) Acoustic attenuation $\alpha = \omega^2*\tau)/(2*U)$ --------(7)
(viii) Lennard Jonne's potential $n = (6V_m/V_a) - 13$ --------(8)

Where, U=ultrasonic velocity (m/s), ρ=density (Kg/m^3), η=viscosity ($Kgm^{-1}s^{-1}$), K=temperature dependent Jacobson's constant, V_m= molar volume (m^3), V_a= available volume (m^3), $\omega = 2\pi f$

4. Results and Discussion

The calculated parameters such as adiabatic compressibility, intermolecular free length, specific acoustic impedance, relaxation time, relative association, absorption coefficient, acoustic attenuation and Lennard Jonne's potential were presented in table – 1.

Table-1 Acoustical parameters of sodium dodecyl sulphate (10 mm) with different concentrations of filler sodium chloride (2mm to 14 mm) at various temperatures (298°K to 328°K)

Temp (° K)	Molality (mm)	$\beta*10^{-10}$ ($Kg^{-1}ms^2$)	L_f*10^{-10} (m)	$Z*10^6$ ($Kgm^{-2}s^{-1}$)	$\tau*10^{-13}$ (s)	R_A	α/f^2*10^{-15} ($Npm^{-1}s^2$)	N	$\alpha*10^3$
298	2	4.4987	0.4210	1.4898	5.5471	1.0030	7.3315	75.888	29.326
	4	4.4681	0.4195	1.4950	5.5779	1.0020	7.3475	80.203	29.390
	6	4.4011	0.4164	1.5067	5.5442	1.0001	7.2498	91.347	28.999
	8	4.3305	0.4130	1.5192	5.5089	0.9977	7.1469	107.000	28.588
	10	4.2727	0.4103	1.5297	5.4667	0.9959	7.0457	124.142	28.183
	12	4.2295	0.4082	1.5382	5.4746	0.9954	7.0238	139.381	28.095
	14	4.1874	0.4061	1.5467	5.4782	0.9948	6.9964	158.428	27.986
	2	4.3739	0.4214	1.5081	4.3348	1.0028	5.6384	101.285	22.554

	4	4.2706	0.4164	1.5264	4.2466	0.9992	5.4589	132.454	21.836
	6	4.2567	0.4157	1.5294	4.2891	0.9994	5.5208	141.338	22.083
308	8	4.2084	0.4133	1.5389	4.3183	0.9987	5.5152	158.428	21.061
	10	4.1861	0.4122	1.5431	4.3088	0.9980	5.4888	171.615	21.956
	12	4.1732	0.4116	1.5459	4.3173	0.9980	5.4924	179.000	21.97
	14	4.1576	0.4108	1.5497	4.3117	0.9988	5.4783	187.000	21.913
	2	4.3016	0.4241	1.5174	3.5657	1.0004	4.5899	128.176	18.359
	4	4.2498	0.4215	1.5269	3.5279	0.9988	4.5145	149.711	18.058
	6	4.2328	0.4207	1.5301	3.4999	0.9983	4.4935	158.428	17.976
318	8	4.1648	0.4173	1.5431	3.5217	0.9964	4.4631	205.181	17.853
	10	4.1408	0.4163	1.5480	3.5412	0.9962	4.4762	227.000	17.905
	12	4.1186	0.4150	1.5524	3.5304	0.9956	4.4512	253.666	17.805
	14	4.0756	0.4128	1.5608	3.5240	0.9942	4.4205	329.357	17.682
	2	4.2766	0.4291	1.5183	2.8858	1.0009	3.6953	147.000	14.781
	4	4.2301	0.4267	1.5271	2.8655	0.9997	3.6505	171.615	14.602
	6	4.2019	0.4253	1.5324	2.8745	0.9989	3.6500	191.255	14.600
328	8	4.1323	0.4218	1.5453	28369	0.9961	3.5721	269.352	14.289
	10	4.1032	0.4203	1.5513	2.8273	0.9958	3.5492	318.034	14.197
	12	4.0635	0.4182	1.5595	2.8276	0.9951	3.5341	423.363	14.137
	14	4.0112	0.4155	1.5699	2.8147	0.9933	3.4954	787.000	13.982

The variations of ultrasonic velocity were found to increase with mole fraction of sodium chloride as in figure-1. The velocity variation may be attributed to the molecular association of molecules. The hydrogen bonded structure of water is disrupted by the addition of solute particles such as SDS and NaCl. The electrolytes occupy the interstitial space of water and tend to break the original ordered state of water. Velocity also increases with the rise in temperature due to the cohesion brought about by the ionic hydration effect.
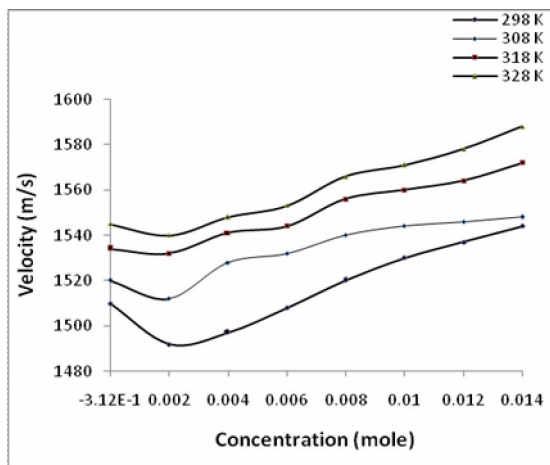

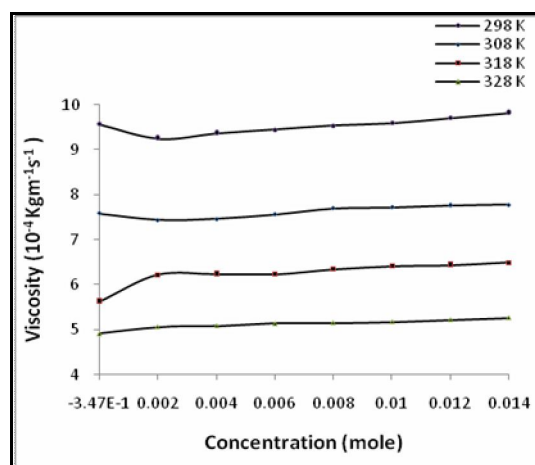Fig: 1 Concentration vs Velocity

Fig: 2 Concentration vs Viscosity

The viscosity values as represented in figure-2 increases with the mole fraction of NaCl and decreases with the increase of temperature, which shows decrease in intermolecular forces due to the rise in thermal energy of the system.

The adiabatic compressibility exhibits exactly the reverse trend of velocity as shown in figure-3. The decrease in adiabatic compressibility is attributed to the fact that soap molecules ionize in dilute solutions. These ions are surrounded in solution by a layer of solvent molecules, firmly bounded and oriented towards the ions. The orientation of solvent molecules around the ions is attributed to the influence of the electrostatic field of ions, which lowers the compressibility of the solution, i.e., the solutions become harder to compress.

The decrease in intermolecular free length with increasing mole fraction of NaCl, which is shown in figure-4, is an indication of the increase in intermolecular forces with the addition of soap-forming aggregates

of solvent molecules around solute ions, supporting the strong solute-solvent interactions affecting the structural arrangements [16].
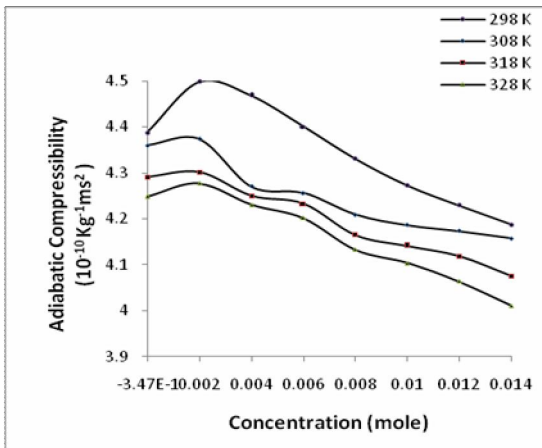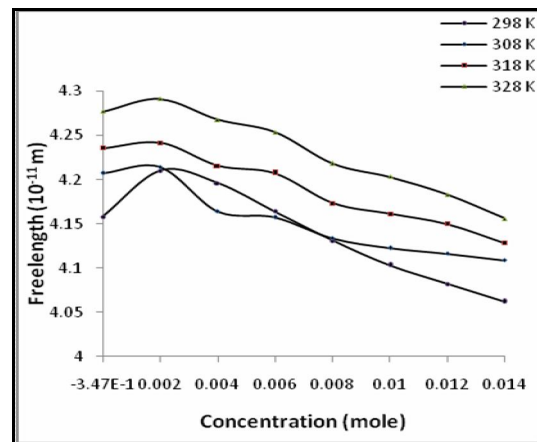

Fig: 3 Concentration vs Adiabatic Compressiblity   **Fig: 4 Concentration vs Freelength**

When an acoustic wave travels in a medium, there is a variation of pressure from particle to particle. The ratio of the instantaneous pressure excess at any particle of the medium to the instantaneous velocity of that particle is known as acoustic impedance of the medium [17]. The increase of acoustic impedance represented by figure-5 is an indication of strong and effective interaction between NaCl and aqueous surfactant solutions.
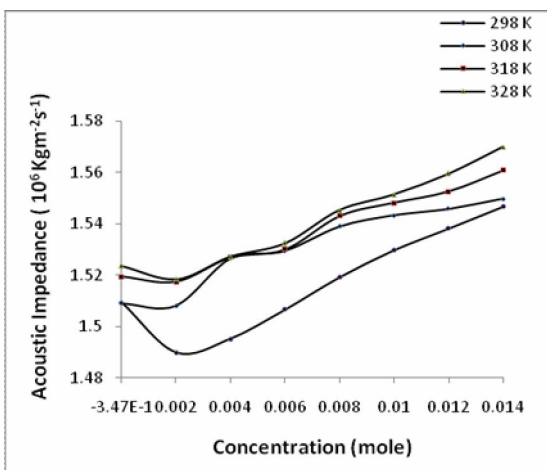
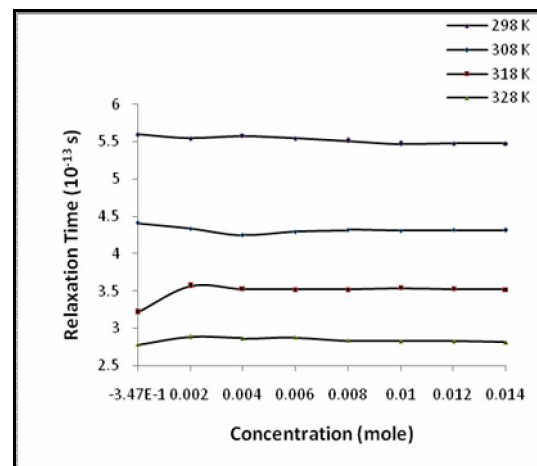**Fig: 5 Concentration vs Acoustic impedance**   **Fig: 6 Concentration vs Relaxation time**

Relaxation time occurs due to the structural relaxation process [18] and in such a situation, the molecules may be rearranged due to the cooperative process [19]. Acoustical relaxation time shown in figure-6 is directly proportional to viscosity and it shows non linear variation at lower temperatures and becomes linear at higher temperatures, due to the formation of hydrogen bonding between hydroxyl group (-OH) of water and – CH group of SDS, with Na^+ and Cl^- ions of sodium chloride. It decreases with rise in temperature which shows the instantaneous conversion of excitation energy to translational energy, when the temperature is increased.
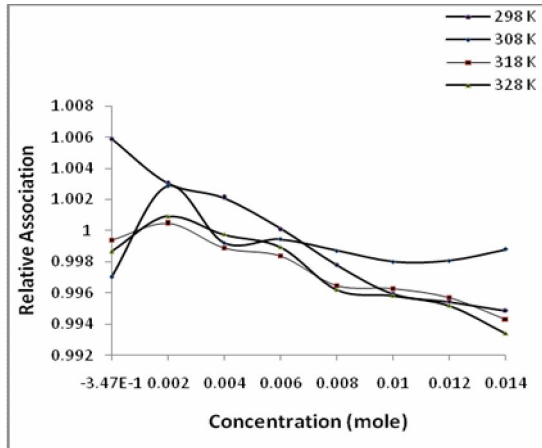
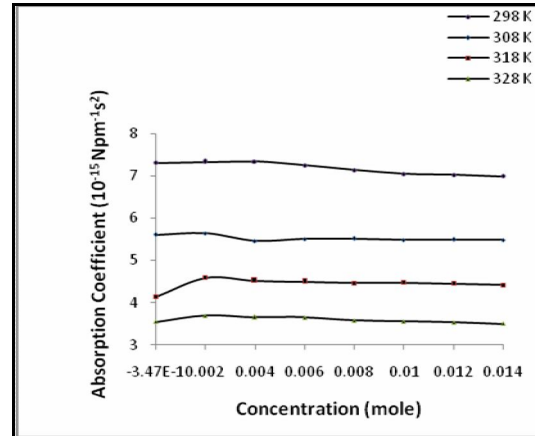Fig: 7 Concentration vs Relative Association

Fig: 8 Concentration vs Absorption Coefficient

The decrease in relative association with concentration has been attributed either to the decreased association between NaCl and aqueous surfactant molecules at higher concentration, or to increased solvation of ions. It is represented in figure-7. The absorption coefficient given in figure-8 decreases with increase of concentration and temperature whose variation is similar to that of adiabatic compressibility.
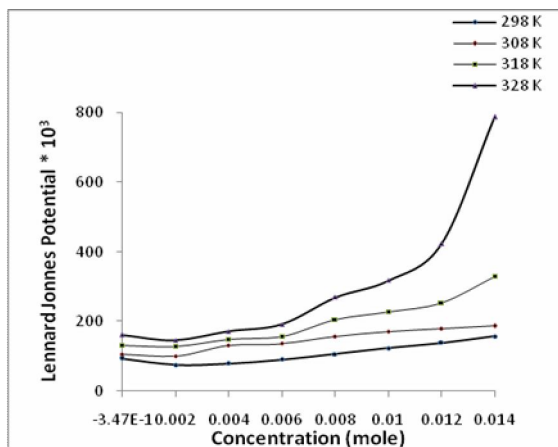

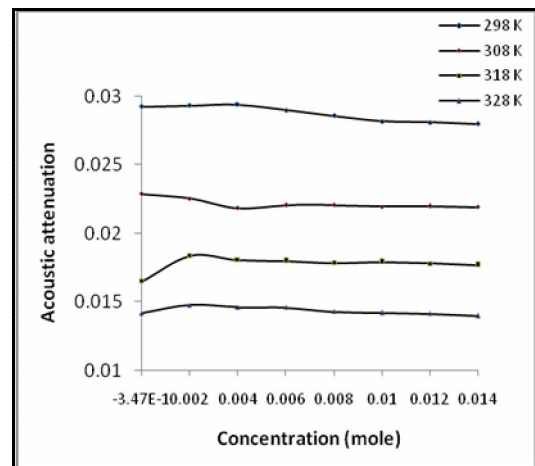Fig: 9 Concentration vs Lennard Jonnes Potential

Fig: 10 Concentration vs Acoustic attenuation

Lennard Jonne's potential is defined as the magnitude of the repulsion forces of molecules that describes the individual exponent for each liquid or solution. It increases with increase of mole fraction of NaCl and temperature which shows that repulsive forces becomes smaller than that of attractive forces resulting in stronger association of surfactant and NaCl molecules. It is graphically shown in figure-9. The value of acoustic attenuation decreases with concentration and temperature whose variation shown in figure-10 is in accordance with the velocity values. It is greatly influenced by the velocity and frequency values.

In the above surfactant and filler solution the following interactions may be presumed,

(i)   Ion-dipolar/hydrophilic group interactions between the ions of sodium chloride (Na^+, Cl^-) and H^+ , OH^- groups of water.
(ii) Hydrophilic-ionic interaction between the ions of sodium chloride and polar parts of water.
(iii) Hydrophilic-hydrophobic interaction between the Na^+, Cl^- group of sodium chloride and Na^+, alkyl chain (CH3 (CH2)n) group of surfactant SDS.

5. Conclusions

In the light of the above observations and calculated acoustical parameter values it may be concluded that there exists a stronger interactions and associations between the aqueous surfactant SDS molecules and filler NaCl molecules. The existence of ion-solvent or solute-solvent interactions resulting in attractive forces

which promote the structure making tendency, while ion-ion or solute-solute interactions are resulting in dipole-dipole, dipole-induced dipole and electrostrictive forces which enhances the structure breaking properties of surfactant solutions. It is found from the present investigation that interactions between the filler molecules and aqueous SDS molecules are more than the other ionic interactions. Hence the addition of filler NaCl to surfactant enhances the efficiency of SDS by the stronger associations and structural making capacity.

Acknowledgement

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