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Studies of Acoustical Parameters on Rose Bengal, Brilliant Congo and Diamine Fast Scarlet

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The ultrasonic velocities (U) and densities (ρ) were measured for three dyes namely rose Bengal, brilliant Congo and diamine fast scarlet in aqueous solution at various temperatures by keeping concentration constant and *vice-versa*. The various acoustic parameters, such as adiabatic compressibility (β), intermolecular free length (L_f) and specific acoustic impedance (Z) were computed from the experimental data.

Key Words: Rose Bengal, Brilliant Congo, Diamine fast scarlet, Ultrasonic velocity, Adiabatic compressibility.

INTRODUCTION

The ultrasonic technique has been used for studying the solute-solvent interactions in a number of systems, including organic[1] low melting solids[2] and complex formation[3, 4]. The propagation of ultrasonic waves and the measurement of velocity[5–8] and absorption[9] in inorganic, organic and organo-metallic binary systems have been used to access the molecular interactions in these systems. The variation of ultrasonic velocity and other acoustic parameters with temperature has been studied using a diffraction technique[10]. Several workers[11–13] have used ultrasonic velocity measurements for studying ion-solvent interactions. Ultrasound has been used by several workers to determine the solute-solvent interactions in aqueous solutions. A number of workers have reported the ultrasonic studies on different types of soaps and detergents[14–18]. According to Eyring *et al.*[19, 20] molecules in liquid state are so loosely packed as to leave some free space in between them. This free space and its dependent properties are related to the molecular strucutre and may show some interesting features about the interaction, which may occur among liquids.

The present work deals with ultrasonic velocity and density measurements of aqueous solutions of various dyes namely rose bengal, brilliant congo and diamine

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fast scarlet at various concentrations by keeping temperature constant and *vice-versa.* The dependence of these parameters is found to be useful in understanding the nature and extent of interaction between molecules. Physico-chemical properties can be understood among the interacting components from ultrasonic velocity measurements and it can be coupled with other experimental data such as density and viscosity to calculate various acoustical parameters like adiabatic compressibility, free length, free volume and internal pressure, which are useful in understanding the molecular interactions in binary and ternary mixtures[21-25].

EXPERIMENTAL

The dyes rose bengal, brilliant congo and diamine fast scarlet were provided by Sigma Aldrich Chemical Co. All solutions were prepared in double distilled water. Experimental solutions were freshly prepared and thermostated before ultrasonic velocity and density measurements.

A multifrequency ultrasonic interferometer (Mittal Enterprises, New Delhi, Model MX-4) operating at a frequency of 3 MHz was used to measure the ultrasonic velocity of the experimental solutions. The maximum uncertainty of the velocity was ± 0.1 m s^{-1}. Densities of the solutions were measured accurately using 25 mL specific gravity bottle in an electronic balance with an accuracy of ± 0.1 mg. The temperature of the solutions were maintained upto ± 0.5°C by circulating thermostated water around the cell with the help of 'Technico' thermostat. The pH of the medium in all solutions was kept constant (pH 5.5) using acetate buffer.

Computational Method

The various acoustic parameters, namely adiabatic compressibility[26] (β), intermolecular free length[27] (L_f) and specific acoustic impedance[28] (Z) were calculated using the following relationships:

$$\beta = 1/U^2\rho \text{ m}^2 \text{ N}^{-1}$$

$$L_f = K/U\rho^{1/2} \text{ m}$$

$$Z = U\rho \text{ kg m}^2 \text{ s}^{-1}$$

where U and ρ are the ultrasonic velocity and density and K is the temperature dependent Jacobson's constant which is given as $(93.875 + 0.345T) \times 10^{-9}$ and T is the temperature in Kelvin.

RESULTS AND DISCUSSION

Ultrasonic velocity and adiabatic compressibility can be measured with great accuracy and consequently provide a powerful tool for the prediction of inter-molecular interactions. From Figs. 1 and 2, it can be seen that the ultrasonic velocity increases (or the adiabatic compressibility decreases) non-linearly with increasing concentration of dyes. This can be explained by resorting to flickering cluster model of water[29]. When the dye is dissolved in water, the dye molecules

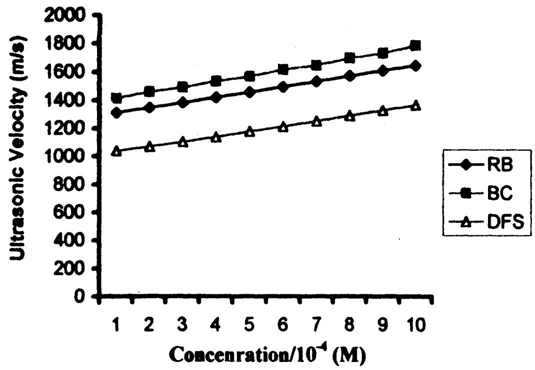

Fig. 1. Plot of ultrasonic Velocity *vs.* conc. of RB, BC, DFS

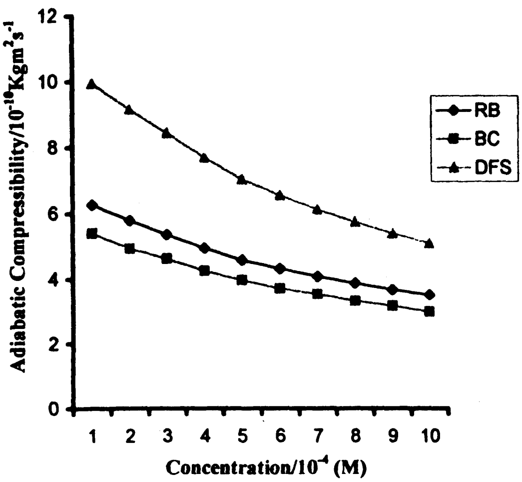

Fig. 2. Plot of adiabatic comressibility *vs.* conc. of RB, BC, DFS

would first disrupt the open structure organization leaving the molecules in closely fitted helical cavities[30]. The dye molecules can occupy both the nodes and voids of the water framework. Such an increase in close packed structures of water results in increased cohesion of water molecules leading to decrease in compressibility. This also results in increase of ultrasonic velocity.

However, the adiabatic compressibility (β), intermolecular free length (L_f) and acoustic impedance (Z) decrease with increase of concentration at constant temperature 303 K (Table-1). The motion of dye macromolecule is affected by mutual interactions between macromolecules with one another. Indirectly, the first type of mutual interaction is termed as hydrodynamic screening, which is significant in determining the viscous flow properties of dilute solution. In more concentrated solution direct segment- segment interaction will exist[31]. The interaction giving rise to association between the two types of molecules of dyes and water may be responsible for the increase in ultrasonic velocity.

TABLE-1
ULTRASONIC VELOCITY, DENSITY, ADIABATIC COMPRESSIBILITY, ACOUSTIC IMPEDANCE AND INTERMOLECULAR FREE LENGTH OF ROSE BENGAL + WATER AND BRILLIANT CONGO + WATER AT 303 K

	Rose Bengal + water					Brilliant Congo + Water				
Conc./ 10^{-4} (M)	U ($m s^{-1}$)	ρ (kg m^{-3})	$\beta/10^{-10}$ ($m^2 N^{-1}$)	$Z/10^6$ (kg $m^2 s^{-1}$)	L_f (nm)	U ($m s^{-1}$)	ρ (kg m^{-3})	$\beta/10^{-10}$ ($m^2 N^{-1}$)	$Z/10^6$ (kg $m^2 s^{-1}$)	L_f (nm)
1	1310.4	928.3	6.27	1.21	0.0496	1412.8	928.4	5.40	1.31	0.0460
2	1346.4	951.8	5.79	1.28	0.0481	1458.4	951.9	4.93	1.35	0.0440
3	1382.4	975.4	5.36	1.34	0.0463	1489.2	975.4	4.62	1.45	0.0426
4	1419.6	1001	4.95	1.42	0.0445	1533.6	1001	4.25	1.53	0.0408
5	1456.8	1027	4.58	1.49	0.0428	1564.8	1027	3.97	1.60	0.0382
6	1494.4	1035	4.32	1.54	0.0416	1613.6	1035	3.71	1.67	0.0382
7	1532.0	1044	4.08	1.59	0.0404	1644.4	1044	3.54	1.71	0.0373
8	1570.4	1046	3.87	1.64	0.0394	1696.4	1046	3.32	1.77	0.0361
9	1608.8	1049	3.68	1.68	0.0384	1732.4	1049	3.17	1.81	0.0343
10	1644.6	1050	3.52	1.72	0.0375	1784.4	1050	2.99	1.87	0.0343

At low concentration dye-water interaction dominates whereas at high concentration dye-dye interaction dominates. Though the dye-solvent interaction may result from hydrogen bonding, dispersion and polar effects at lower concentration, the interactions like hydrogen bonding which dominates as the dye is polar in nature. This indicates an increase in the effective size of the molecule in the path of ultrasonic wave. This is due to the complex formation between several dye macromolecules and water molecules.

The ultrasonic velocity of a dye in water normally decreases with increase in temperature, which is a general feature, observed in organic liquids due to weakening of the intermolecular forces by the thermal energy. Kapustin[32] described this trend in ultrasonic velocity with temperature (Figs. 3 and 4) as due

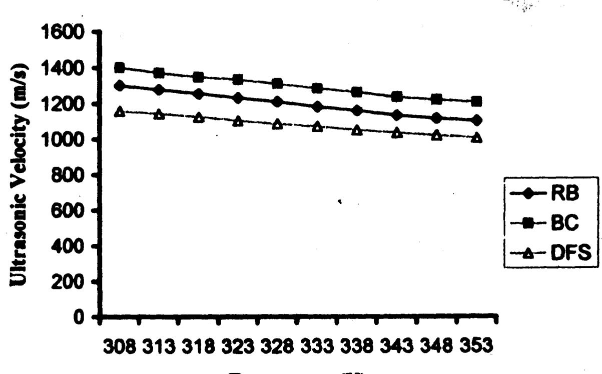

Fig. 3. Plot of Ultrasonic Velocity *vs*. Temp. of RB, BC, DFS

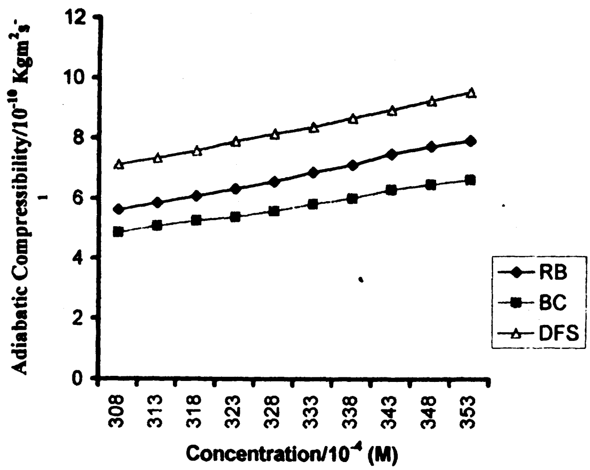

Fig. 4. Plot of Adiabatic Compressibility *vs.* Temp. of RB, BC, DFS

to the increase of mean distance between the molecules and decrease of potential energy of interaction (Table-2).

TABLE-2
ULTRASONIC VELOCITY, DENSITY, ADIABATIC COMPRESSIBILITY, ACOUSTIC IMPEDANCE AND INTERMOLECULAR FREE LENGTH OF ROSE BENGAL + WATER AND BRILIANT CONGO + WATER AT 10^{-4}M

	Rose Bengal + water					Brilliant Congo + water				
Temp. (K)	U (m s^{-1})	ρ (kg m^{-3})	$\beta/10^{-10}$ (m^2 N^{-1})	$Z/10^6$ (kg m^2 s^{-1})	L_f (nm)	U (m s^{-1})	ρ (kg m^{-3})	$\beta/10^{-10}$ (m^2 N^{-1})	$Z/10^6$ (kg m^2 s^{-1})	L_f (nm)
308	1303	1045.0	5.63	1.36	0.0475	1402	1044.8	4.86	1.46	0.0441
313	1279	1044.4	5.85	1.33	0.0483	1372	1044.2	5.08	1.43	0.0455
318	1255	1043.8	6.08	1.30	0.0502	1349	1043.6	5.26	1.40	0.0467
323	1231	1043.2	6.32	1.28	0.0516	1334	1043.0	5.38	1.39	0.0476
328	1209	1042.6	6.56	1.26	0.0530	1311	1042.4	5.58	1.36	0.0489
333	1182	1041.9	6.86	1.23	0.0547	1285	1041.7	5.81	1.33	0.0533
338	1161	1041.2	7.12	1.20	0.0561	1264	1041.0	6.01	1.31	0.0516
343	1133	1040.5	7.48	1.17	0.0580	1236	1040.3	6.29	1.28	0.0532

The adiabatic compressibility (β) values calculated from ultrasonic velocity and density measurements for the dyes indicate that adiabatic compressibility value increases with increase in temperature in all the dyes indicating the weakening intermolecular forces among dye molecules. The intermolecular free length (L_f) values increase with increase in temperature indicating the weakening of intermolecular forces among dye molecules in water. Compressibility factor shows a unique behaviour confirming higher molecular interaction, hence all the dyes used are capable of undergoing degradation.

This study is thus much helpful to find a method of decomposing dyes for environment friendly nature. The role of dyes in the modern world occupies a dominant role in all walks of life. Therefore, innumerable number of dyes is used for colouring fabrics, foodstuffs and drugs. Therefore, it is necessary to find out the effects of dyes on the environment. If the dyes are susceptible to degradation after use, then the environmental pollution can be curtailed. Hence ultrasonic studies are conducted on selected three dyes which are widely used.

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