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Study of Acoustic and Thermodynamic Properties of Aqueous Solution of Dextran at Different Concentration and Temperature through Ultrasonic Technique

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Abstract: ***The thermo acoustic parameters like internal pressure (Πi), absorption coefficient or attenuation coefficient (α), free volume (V_f), Rao's constant (R) and Wada's constant (W) have been calculated using the experimentally measured values such as ultrasonic velocity, density and viscosity of aqueous dextran solution of different concentrations at five different temperatures ranging from 303K-323K at 1MHz frequency. The variation of these parameters with respect to concentration and temperature have been studied which throw light into the structural rearrangement of solute (dextran) and solvent (distilled water) in aqueous solution.***

Keywords: Aqueous dextran solution, Ultrasonic Velocity, Internal pressure (Πi), Absorption coefficient or attenuation coefficient (α), Free volume(V_f), Rao's constant (R), Wada's constant (W)

1. Introduction

Ultrasonic investigation of aqueous solution of dextran containing polar and non-polar components is of considerable importance in understanding intermolecular interaction between the solute and solvent molecules as that finds application in several industrial and technological processes [1] Ultrasonic velocity and the derived acoustical parameters like adiabatic compressibility, Internal pressure (Πi), Absorption coefficient or attenuation coefficient (α), Free volume (V_f), Rao's constant (R), Wada's constant (W) provide valuable information about the molecular environments. This has been studied with respect to variation in concentration of the solution and temperatures.

Measurement of some bulk properties like viscosity (η),density(ρ) and ultrasonic velocity (U) provides insight into the intermolecular arrangements of the solute and solvent in solutions and helps to understand the thermodynamic and acoustic properties of the solutions.
In this paper, values of η, ρ, U and related thermodynamic and acoustic parameters have been determined and the solute-solvent interactions for the aqueous solution of dextran of different concentration have been studied at five different temperatures i.e. 303K, 308K,313K, 318K & 323K at 1MHz frequency. Dextran is a branched polysaccharide which is water soluble .Dextran and their derivatives find wide applications in various industries particularly in pharmaceutical sector [2]

The fast increasing of these polyglucosans for medical, industrial and research purpose motivated to carry out investigation of thermo acoustic parameter of dextran by ultrasonic technique.

2. Methods

Freshly prepared distilled water has been used as solvent for preparing dextran solution. Dextran of molecular weight 70,000 used as solute, is of analytical reagent (AR) grade, manufactured by HI Media Laboratories Private Limited, India. Velocity, density and viscosity have been measured following the standard procedure [3] using an ultrasonic interferometer (Model M-84, supplied by M/S Mittal Enterprises, New Delhi), a 25-ml specific gravity bottle and an Oswald viscometer respectively

3. Theoretical Aspect

The following thermodynamic and acoustic parameters were calculated:

1. Internal pressure (π_i): It can be calculated using the relation [4] as given below

$$\pi = \mathrm{bRT}\left(\frac{\mathrm{k}\eta}{\mathrm{U}}\right)^{3/2}\left(\frac{\rho^{2/3}}{\mathrm{M_{eff}}^{7/6}}\right)$$

Where b stands for cubic packing, which is assumed to be 2 for all liquids, k is a dimensionless constant independent of temperature and nature of liquids. Its value is 4.281×10^9. T is the absolute temperature in Kelvin, M_{eff} is the effective molecular weight, R is the universal gas constant, η is the viscosity of solution in $Ns \cdot m^{-2}$, U is the ultrasonic velocity in $m \cdot s^{-1}$, and ρ is the density in $kg \cdot m^{-3}$ of solution.

2. Absorption coefficient or attenuation coefficient: It is a characteristic of the medium and depends on the external condition like temperature, pressure, and frequency of measurement. It is given by the following [5] relation

$$\propto = \frac{8\pi^2\eta f^2}{3\rho U^3}$$

Where f is the frequency of ultrasonic wave.

3. Free volume (V_f) The free volume is broadly defined as the average volume in which the molecules can move inside the hypothetical cell due to the repulsion of the surrounding molecules have given[6-7] a relation for the calculation of free volumes of liquids from the velocity of sound in liquid (U) and the viscosity (η) of liquid as follows [9]

$$V_f = \left(\frac{\mathrm{M_{eff}}\,\mathrm{U}}{\mathrm{K}\eta}\right)^{\frac{3}{2}}$$

Where M_{eff} is the effective molecular weight of the mixture ($M_{eff} = \Sigma miXi$, where mi and Xi are the molecular weight and mole fraction of individual constituents respectively), K is a temperature independent constant which is equal to 4.281×10^9 [10] for all liquids

4. Rao's constant: Rao established the empirical relation between molecular weight, density and ultrasonic velocity of liquids as

$$\mathrm{R} = \frac{\mathrm{M_{eff}}}{\rho}\mathrm{U}^{1/3}$$

This equation is called Rao's rule and R is also called as the molar sound velocity. A number of authors have provided a theoretical explanation of Rao's formula on the basis of phase rule and kinetic theory of liquids.

5. Wada's constant: Wada had analyzed the variation of molar compressibility with concentration for many liquid systems and has derived the empirical relation,

$$\mathrm{W} = \frac{\mathrm{M_{eff}}}{\rho}\ \beta^{-1/7}$$

4. Results and Discussion

The density, viscosity, ultrasonic velocity and adiabatic compressibility of aqueous solution of dextran of different concentration and temperature have been used [11] to calculate some thermodynamic and acoustic parameters. Internal pressure and attenuation coefficient have been calculated and represented in table 1.

Table 1: Values of **Internal pressure** and **Attenuation coefficient** of aqueous solution of Dextran at different temperatures and concentrations at 1MHz. frequency

T (Kelvin)	Internal pressure(($\times 10^3$ $N \cdot m^{-2}$)					Attenuation coefficient($x10^6$($np \cdot m^{-1}$)				
	0.10%	0.25%	0.50%	0.75%	1%	0.10%	0.25%	0.50%	0.75%	1%
303	841.075	846.832	864.436	872.110	903.613	6.371	6.469	6.758	6.924	7.445
308	795.255	805.302	825.704	836.903	866.981	5.469	5.611	5.932	6.105	6.572
313	776.564	784.503	803.298	819.955	835.776	5.019	5.122	5.410	5.634	5.869
318	756.370	763.533	785.849	794.302	813.512	4.593	4.694	4.985	5.111	5.401
323	733.322	741.552	756.463	765.089	803.493	4.173	4.283	4.484	4.598	5.079

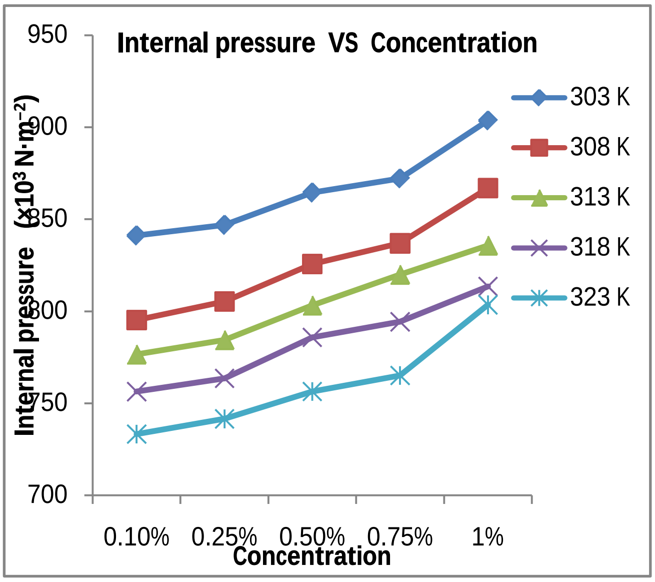

Fig.-1 Variation of **internal pressure** with **concentration**

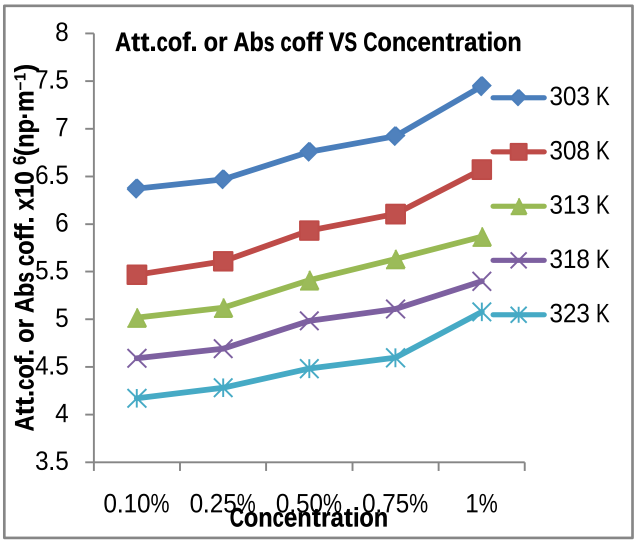

Fig.-3 Variation of **attenuation coefficient** with **concentration**

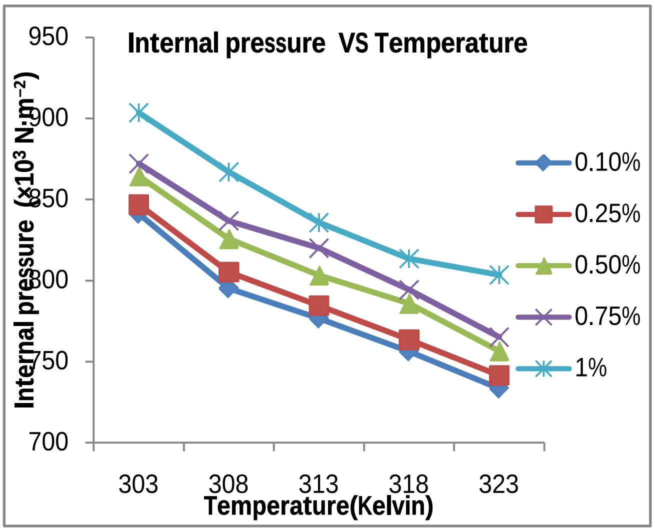

Fig.-2 Variation of **internal pressure** with **temperature**

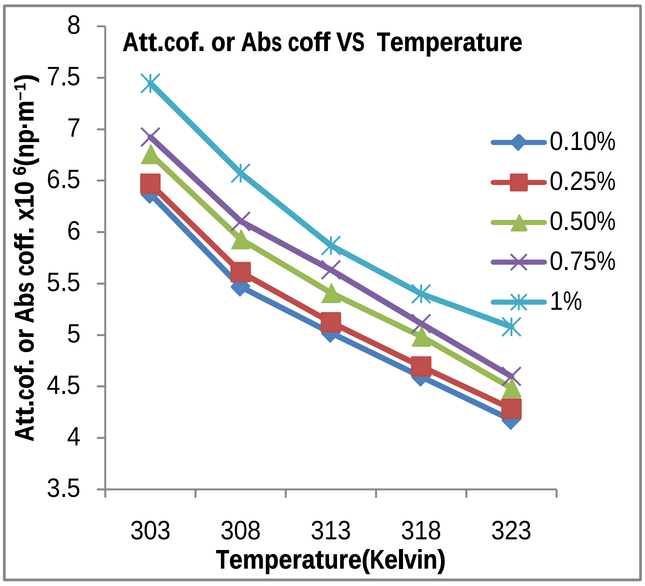

Fig.-4 Variation of **attenuation coefficient** with **temperature**

Internal pressure is a broader concept and is a measure of the totality of the forces of interaction that contribute to the overall cohesion / adhesion of the liquid system. When concentration of dextran increases, internal pressure increases as the force of cohesion increases as Fig.-1. When the temperature is increased there is reduction in molecular interaction as they move away from each other. This reduces the cohesive force thus a decrease in internal pressure as shown in Fig.-2.

Variation in the **attenuation coefficient** is a measure of spatial rate of decrease in the intensity level of the ultrasonic wave. When concentration of dextran increases, the attenuation coefficient increases and it decreases with increase in temperature. The effect of temperature on attenuation is more than that of concentration.

From the experimentally measured values[11] of viscosity and velocity the free volume of aqueous solution of dextran have been calculated and represented in table 2.

Table 2: Values of Free volume (V_f) of aqueous solution of dextran at 1MHz frequency at different temperatures and concentrations.

T (Kelvin)	Free volume(Vf) $(x10^{-3}m^{3}\cdot mol^{-1})$				
	0.10%	0.25%	0.50%	0.75%	1%
303	0.397	0.406	0.435	0.453	0.511
308	0.326	0.340	0.371	0.390	0.439
313	0.296	0.307	0.332	0.357	0.384
318	0.266	0.275	0.301	0.316	0.344
323	0.235	0.244	0.261	0.275	0.321

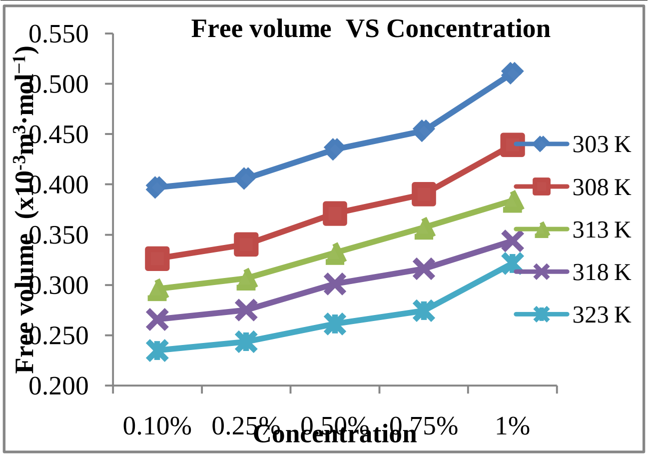

Fig.-5 Variation of Free volume (Vf) with Concentration

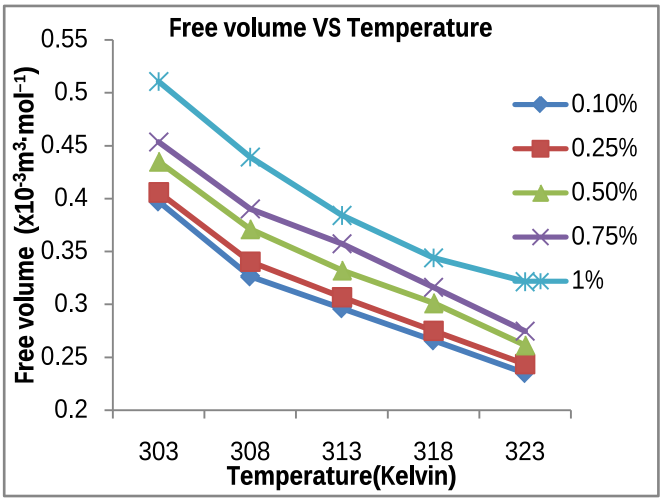

Fig.-6 Variation of Free volume (V_f) with Temperature

Free volume is one of the significant factors in explaining the free space and have close connection with molecular structure and it may show interesting features about interactions between solute(dextran) and solvent(distilled water).Fig-5 and Fig-6 shows that free volume increases with increase in concentration and decreases with increase in temperature respectively. When concentration of solute increases, due to hydrogen bonding in water the molecules of solute may arranged in the solvent in such a way that void space may not be available due to which solute becomes less compressible and hence free volume increases. Increase in free volume shows solute-solvent interaction in solution[12].

Using the experimentally measured values of density and velocity [11] Rao's constant and Wada's constant of aqueous solution of dextran have been calculated and represented in table 3.

Table 3: Values of Rao's constant(R) and Wada's constant(W) at different temperatures and concentrations in aqueous solution of Dextran at 1MHz. frequency

T (kelvien)	Rao's constant R $(m^3/mole)(m/s)^{1/3}(10^{-3})$					Wada's constant W $(m^3/mole)(N/m^2)^{1/7}(10^{-3})$				
	0.10%	0.25%	0.50%	0.75%	1%	0.10%	0.25%	0.50%	0.75%	1%
303	207.773	207.889	208.028	208.484	208.809	393.064	393.072	393.703	394.584	395.253
308	208.515	208.574	209.008	209.213	209.605	394.267	394.448	395.292	395.767	396.558
313	209.280	209.461	209.828	209.999	210.526	395.506	395.886	396.622	397.042	398.039
318	210.231	210.453	210.455	211.020	211.356	397.046	397.492	397.639	398.697	399.385
323	210.976	211.049	211.470	212.011	212.234	398.253	398.457	399.283	400.304	400.809

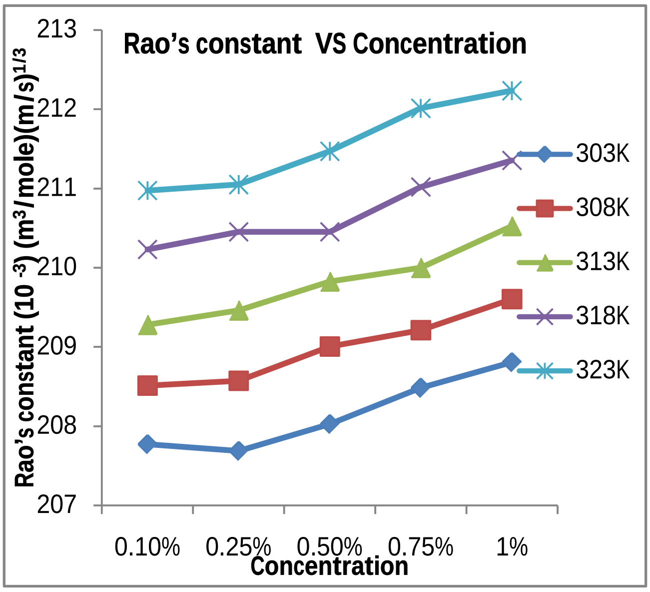

Fig.-7 Variation of **Rao's constant** (R) with **concentration**

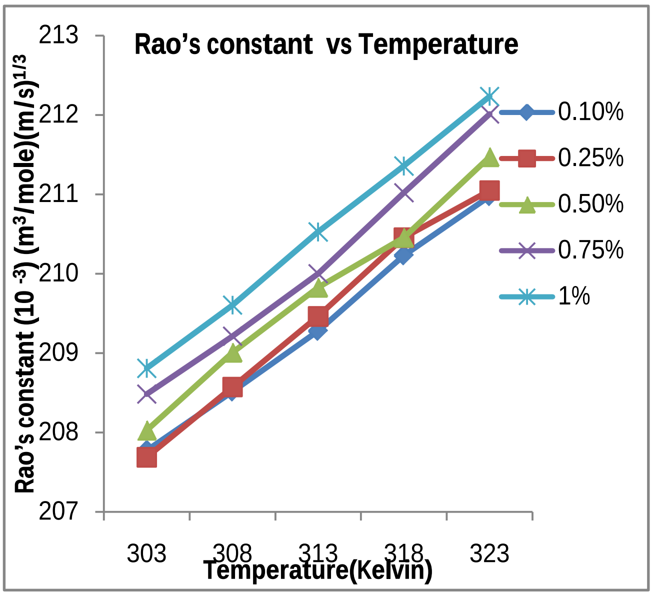

Fig.-8 Variation of **Rao's constant** (R) with **Temperature**

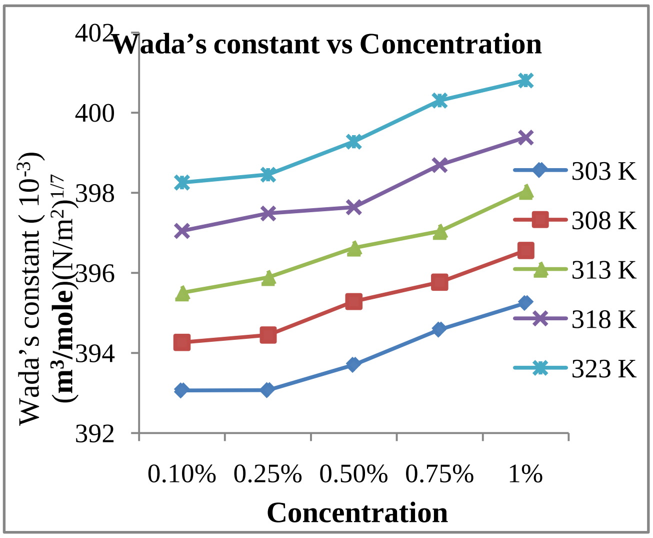

Fig.-9 Variation of **Wada's constant** (W) with **concentration**

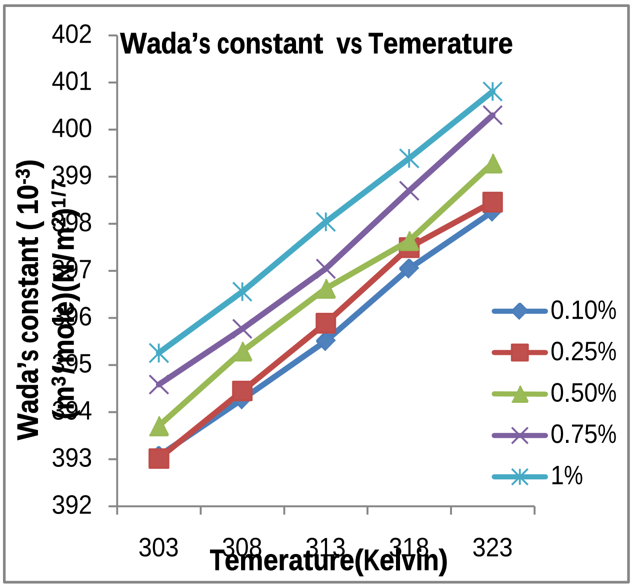

Fig.-10 Variation of **Wada's constant** (W) with **Temperature**

Rao's constant or molar sound velocity shows an increase trend with increase in concentration and temperature. The increasing trends of molar sound velocity and Wada's constant or molar compressibility with concentration suggest the availability of more number of components in a given region thus leading to a close packing of the medium there by increasing the interactions shows strong solute-solvent interaction existing in the solution.

Conclusions

From the experimentally measured parameters (i.e. density, viscosity and ultrasonic velocity) in aqueous solutions of dextran at different concentration and temperature some thermodynamic and acoustic parameters such as internal pressure (Πi), absorption coefficient or attenuation coefficient (α), free volume (V_f), Rao's constant (R), Wada's constant (W) have been calculated at 1MHz frequency .The results show that the specific solute-solvent interactions play an important role for explaining thermo acoustic parameters. However, any deviation from the usual behavior is probably due to characteristic structural changes in the respective system.

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