

Physico-Chemical, Ultrasonic, and Structural Studies on Dextrin with α -Amylase in Aqueous Media At 298.15 K

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Abstract: The ultrasonic velocity, density, and viscosity of dextrin in an aqueous medium at 298.15 K were measured using α -amylase in this study. The measured parameters were used to calculate acoustic/density parameters such as molar volume (V_m), isentropic compressibility (T), thermal expansion coefficient (α_T), relaxation time (t), relaxation strength (r), relative viscosity (r), Enthalpy (H), Activation Energy (G), Surface Tension (σ), van der Waals constant (b), molecular radius (r), Geometrical volume (B), molar surface area (Y), Collision factor (S). Different acoustic magnitudes are computed because they are important in researching unique chemical interactions and theoretical calculations.

Keywords: ultrasonics velocity; derived parameter; molecular interaction; dextrin; amylase.

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1. Introduction

This paper is devoted to researching the physicochemical properties of (amylase + dextrin) mixtures in an aqueous environment as a continuation of earlier work [1-5]. With this goal in mind, our research team conducted a series of tests focusing on binary dextrin solutions to investigate the effect of the glycosyl group, which is used in food, horticulture, and medicinal fields. Our goal is to discuss how the composition and molecular structure affect isentropic compressibility and other acoustic/thermodynamic parameters to gain a better understanding of the factors that provide to the unique behavior of saccharides in an aqueous solvent, where the factors dextrin (amylose –straight chain, and amylopectin crossed chain (fig.1)) and amylase (fig.2) have different molecular natures.

Formulated from the measured above said parameters, many thermodynamical parameters were computed, through which we attempted to explain the physicochemical behavior of the binary mixtures mentioned above to study the magnitude and type of the interactions between the species in the mixture under study [6]. And several parameters were computed, discussed, and interpreted extensively [6-9].

2. Materials and Methods

The solutions were made with Aldrich's AnalaR grade chemicals, then purified using conventional techniques [10]. The percentage of amylase and dextrin solutions created in stages of 1%, ranging from 1% to 6% [higher % leads to incomplete solubility for both samples].

Dextrin solutions range from 1 to 6%, while amylase is 6%, with proportions of (90:10), (50:50), and (10: 90). Throughout the work, we utilized double-distilled deionized water. The prepared solutions were allowed for two hours to reach full stability. (Figure1 and Figure 2).

An Ultrasonic Interferometer operating at 2 MHz (Mittal type - 82, India) at 298.15 K was used to measure the ultrasonic velocity in the mixtures. The sound velocity was accurate within 0.1 m s^{-1} (0.01 percent). A specific gravity bottle (5 ml) and an Ostwald's viscometer (10 ml) were used to determine the density and viscosity of the combination. The density measurement precision was 0.1 kg m^{-3} (0.053 percent), and the viscosity measurement accuracy was 0.001 mNsm^{-2} (0.09 percent).

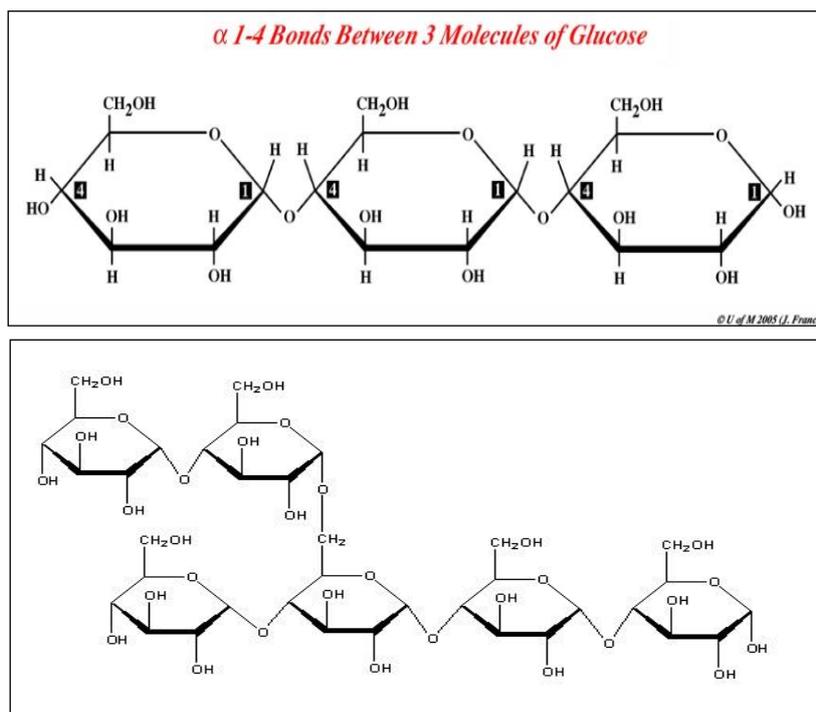


Figure. 1. Structure of (a) amylose and (b) amylopectin.

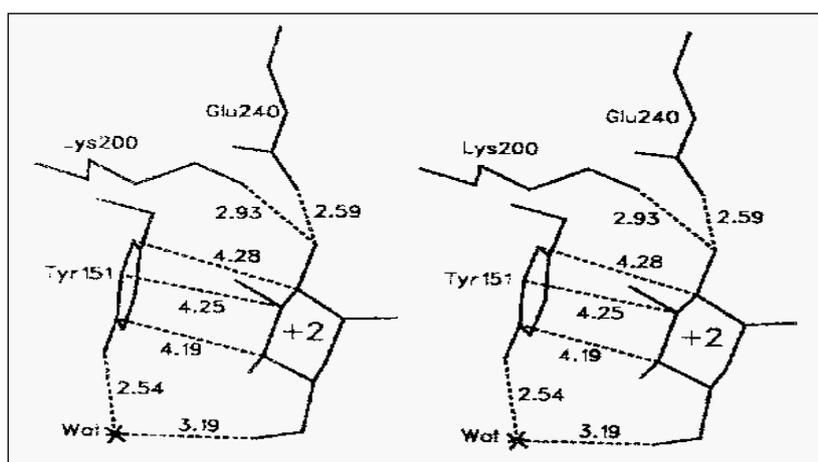


Figure. 2. Structure of amylase.

2.1. Theoretical calculations.

The following relationships have been used to measure, convert, and calculate the measured parameters: the density of the solution,

$$\rho = \frac{m}{m_w} \rho_w \quad [1]$$

Where, ρ , ρ_w and m , m_w are, respectively, the masses and densities of the mixture and water. The cohesiveness of solutions,

$$\eta = \frac{\rho\tau}{\rho_w\tau_w} \eta_w \quad [2]$$

And ρ_s and ρ_w represent the density of the solution and water, respectively, And η_w , ρ_w , and t represent the viscosity, density, and duration of flow of the water, respectively.

The calculations for the ultrasonic velocities come from,

$$\lambda = \frac{2d}{n}, \quad U = \lambda f \quad [3]$$

The following relationships, such as molar volume, which is the volume occupied by a material per unit amount of substance, have been used to calculate the derived parameters.,

$$V_m = \left(\frac{M}{\rho} \right) \quad [4]$$

The degree to which a medium is easily compressed is known as its isentropic

compressibility.
$$\beta_r = \left(\frac{1.71 \times 10^{-3}}{T^{4/9} U^2 \rho^{4/3}} \right) \quad [5]$$

where T, is temperature.

The fractional increase in length in all directions is known as expansivity.

Thermal expansion coefficient
$$\alpha_T = (0.019\beta_r)^{1/4}, \quad [6]$$

Relaxation time
$$t = \left(\frac{4\eta}{3\rho U^2} \right) \quad [7]$$

Relaxation strength
$$\alpha_r = \left(1 - \frac{U_{\text{exp}}^2}{U_{\alpha}^2} \right) \quad [8]$$

were, U_{α} = is taken us 1600 ms^{-1} ,

A measure relative viscosity(η_r) is the measure of the ratio of the viscosity of solution (η_s) and viscosity of solvent (η_o)(applicable only for Newtonian fluids),

Relative viscosity
$$\eta_r = \left(\frac{\eta_s}{\eta_o} \right) \quad [9]$$

In a chemical reaction carried out in the atmosphere, the pressure remains constant, and the enthalpy of the reaction, other words, is computed from the internal pressure (π_i) and molar volume (V_m)

Enthalpy
$$H = \pi_i V_m \quad [10]$$

Activation Energy
$$E_a = RT[\ln \eta V_m] \quad [11]$$

where, R- is the Universal gas constant,

Cohesion is the force of attraction between the molecules of different substances [$\text{H}_2\text{O} + \text{Dextrin with Amylase}$], and it differs for different types of substances since surface tension (σ)

is fundamentally a molecular characteristic. The force of attraction between the molecules of the same substances is known as cohesion, though.

The density and velocity must be known in order to calculate the surface tension.

Surface Tension
$$\sigma = 6.3 \times 10^{-4} U^{3/2} \rho \quad [12]$$

Van der Walls constant
$$b = \frac{M}{\rho} - \left(\frac{RT}{\rho U^2} \right) \left(\left(1 + \frac{MU^2}{3RT} \right)^{1/2} - 1 \right) \quad [13]$$

Molecular radius
$$r = \left(\frac{3b}{16\pi N} \right)^{1/3} \quad [14]$$

where, N- is Avagadro's Number,

Geometrical volume
$$B = \left(\frac{4}{3} \right) \pi r^3 N \quad [15]$$

Molar surface area
$$Y = (36\pi NB^2)^{1/3} \quad [16]$$

Collision factor
$$S = \left(\frac{UV}{BU_\alpha} \right) \quad [17]$$

And

Classical absorption coefficient
$$\left(\frac{\alpha}{f^2} \right) = \left(\frac{8\pi^2 \eta}{3\rho U^3} \right) \quad [18]$$

3. Results and Discussion

Table 1 demonstrates that the observed values of (T) show a similar trend with their values decreasing, indicating that the interaction between the mixing components will become more complex as the percentages grow [11]. Isentropic compressibility is rising (T), and the presence of molecular interactions in other systems is indicated by a modest increase in internal pressure value with concentration [6]. The viscosities of [amylase + dextrin] solution and pure solvent [H₂O] are η and η_0 respectively, and relative viscosity is equal to η/η_0 . The unit of intrinsic viscosity appears to be the inverse of the concentration unit, e.g., dL/g. As the percent of dextrin increases, so do the relaxation time and relative viscosity. Both solute-solvent and solute-solute interactions are indicated by a decrease in r and L_f [5] and an increase in Z [5] with the concentration of solutes. The viscosity data back up this assertion. The value of viscosities rises as concentration rises, implying increasing viscosity [12]. There will be more segment-segment contact in a more concentrated solution with higher molarities [13]. The interaction causing the association between water and dextrin molecules may be responsible for increasing ultrasonic velocity [5], relaxation amplitude, and relaxation time [14]. The growing relaxation amplitude supports structural changes due to entropy fluctuation [15], which may be used to quantify molecular interactions. At all concentrations, relaxation strength diminishes, indicating the formation of aggregates of solvent molecules surrounding the solute, affecting the structural organization of the systems. The rise in relaxation time and absorption coefficient with concentration is conspicuous and noticeable. The nature of molecular interactions derived from the aforementioned parameters' behavior is similar to that derived from the previously reported excess parameters [4,16,17].

Table 1. Measured parameters of various percentages (%) of dextrin with amylase in aqueous media at 298.15

K.									
m	U ms ⁻¹	ρ Kgm ⁻³	η X10 ³ Nsm ⁻²	Vm (m ³ mol ⁻¹)	(β _r) /10 ⁻¹² K ⁻¹ Kg ⁻¹ sm ²	(α _r) /10 ⁻¹² K ⁻¹ Kg ⁻¹ sm ²	t x 10 ⁻¹³ s	(α _r)	η _r
(Amylase + Dextrin) (90 : 10)									
1	1522.0	1.0010	1.0321	18.381	5.9060	1.0292	5.934	0.9512	1.0317
2	1524.5	1.0023	1.0615	18.557	5.8765	1.0279	6.076	0.9215	1.0611
3	1527.6	1.0054	1.0826	18.799	5.8291	1.0259	6.153	0.8849	1.0822
4	1528.5	1.0059	1.1288	19.187	5.8184	1.0254	6.404	0.8738	1.1283
5	1529.4	1.0117	1.2027	19.275	5.7671	1.0231	6.777	0.8633	1.2023
6	1532.6	1.0148	1.3204	19.511	5.7195	1.0210	7.386	0.8251	1.3198
(Amylase + Dextrin) (50 : 50)									
1	1527.5	1.0052	1.1083	18.305	5.8314	1.0260	6.301	0.8857	1.1079
2	1528.4	1.0063	1.1226	18.483	5.8157	1.0253	6.367	0.8753	1.1222
3	1528.8	1.008	1.1393	18.750	5.8001	1.0246	6.449	0.8708	1.1389
4	1530.3	1.0095	1.1541	19.118	5.7769	1.0236	6.509	0.8523	1.1536
5	1530.5	1.0113	1.1711	19.282	5.7614	1.0229	6.591	0.8498	1.1706
6	1532.0	1.0138	1.1871	19.530	5.7312	1.0215	6.652	0.8319	1.1866
(Amylase + Dextrin) (10 : 90)									
1	1522.5	1.0063	1.0521	18.284	5.8607	1.0273	6.014	0.9453	1.0517
2	1524.6	1.0073	1.068	18.465	5.8369	1.0262	6.082	0.9203	1.0676
3	1526.2	1.0087	1.0936	18.738	5.8144	1.0252	6.206	0.9012	1.0931
4	1528.4	1.0098	1.106	19.112	5.7887	1.0241	6.252	0.8750	1.1056
5	1530.3	1.0108	1.1681	19.291	5.7667	1.0231	6.579	0.8523	1.1676
6	1532	1.0115	1.175	19.575	5.7489	1.0223	6.599	0.8325	1.1745

Table 2. Some derived parameters of dextrin with amylase in aqueous media at 298.15 K.

m	(H) (J.mol ⁻¹)	(G) (RT Units)	(σ) dyne cm ⁻¹	(b) (m ³ mol ⁻¹)	(r) 10 ⁻⁸ m	(B)	Y x 10 ¹³ (m ²)	(S)	(α _r ²) x 10 ⁻¹⁴ s ² /m
(Amylase + Dextrin) (90 : 10)									
1	1.0856	1.4391	37.446	15.874	1.16340	39.700	1.0236	4.4041	7.45734
2	1.0905	2.7475	37.588	16.008	1.16666	40.030	1.0293	4.4163	7.42071
3	1.0958	3.7001	37.816	16.168	1.17053	40.440	1.0361	4.4385	7.37606
4	1.1164	5.7617	37.869	16.499	1.17848	41.260	1.0502	4.4420	7.36261
5	1.1116	8.8197	38.121	16.470	1.17778	41.190	1.0490	4.4726	7.34998
6	1.1159	13.4400	38.359	16.621	1.18136	41.568	1.0554	4.4960	7.30411
(Amylase + Dextrin) (50 : 50)									
1	1.0674	4.6672	37.805	15.741	1.16014	39.367	1.0178	4.4391	7.37708
2	1.0749	5.2988	37.882	15.877	1.16346	39.708	1.0237	4.4464	7.36441
3	1.0875	6.0628	37.958	16.080	1.16842	40.220	1.0324	4.4546	7.35900
4	1.1044	6.7905	38.073	16.376	1.17552	40.960	1.0450	4.4648	7.33666
5	1.1109	7.5479	38.149	16.484	1.17811	41.230	1.0496	4.4738	7.33378
6	1.1193	8.3013	38.300	16.655	1.18217	41.650	1.0569	4.4893	7.31226
(Amylase + Dextrin) (10 : 90)									
1	1.0716	2.3016	37.663	15.698	1.15907	39.260	1.0159	4.4317	7.45000
2	1.0778	3.0110	37.778	15.840	1.16256	39.615	1.0220	4.4414	7.41925
3	1.0895	4.1553	37.889	16.056	1.16782	40.155	1.0313	4.4511	7.39595
4	1.1063	4.7742	38.014	16.362	1.17520	40.922	1.0444	4.4614	7.36405
5	1.1125	7.4299	38.123	16.501	1.17852	41.270	1.0503	4.4708	7.33666
6	1.1253	7.8251	38.211	16.736	1.18409	41.858	1.0603	4.4778	7.31226

The viscous relaxation time increases significantly with increasing concentration, and the contact between component molecules is stronger than the attractive forces between component molecules (Tables 1 and 2). The structural relaxation process reveals the presence of molecular interaction, resulting in a relaxation duration of 10-12 s. This trend could be explained because straight-chain molecules rotate less freely than molecules with the appropriate configuration. The fact that relaxation strength varies with concentration shows that the solutions have a lot of solute-solute interactions. These findings are consistent with other researchers [18-20]. The increasing trends in molar volume(Vm), surface tension (σ), and enthalpy (H) indicate the presence of interactions between the constituents of the mixtures.

This fluctuation is due to the transition of dextrin from closed to the open-chain formation, resulting in a reawakening of the solvent-dextrin interaction. The evolution of the other parameters, such as the van der Waals constant (b), geometrical parameters (area, volume, and radius) that increased as the concentration of dextrin increased, as explained above, and, as expected, a decrease in the collision factor under the same conditions, support these conclusions [21,22]. The activation energy (E_a) trends show that requiring less time for the cooperative process or rearranging molecules in mixtures reduces the energy required for dissociation. Gibbs's free energy confirms the same (relaxation time) from the measured values in Table 2. This means that requiring less time for the cooperative process or rearranging molecules in mixtures reduces the energy required for dissociation [23-25].

4. Conclusions

The measured ultrasonic velocity, density, and viscosity values for the binary dextrin aqueous system were used to calculate various acoustic parameters such as isentropic compressibility, relaxation time, relaxation strength, classical absorption coefficient, molar volume, internal pressure, viscous relaxation time, activation energy. According to the findings, at larger molarities, a hydrogen bond forms between a glycosyl bond (C-O-C), and the structure of dextrin changes from closed ring to the straight chain.

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Conflicts of Interest

The authors declare no conflict of interest.

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