STUDY OF VISCOMETRIC, THERMODYNAMIC AND ACOUSTIC PROPERTIES OF SUCROSE IN AQUEOUS SODIUM FLUORIDE

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Abstract

In the current study, interpretations of viscosity, density and ultrasonic velocity of sucrose in aqueous solutions of sodium fluoride at various concentrations were accounted at molarities and temperatures 298.15K and 304.15K. The nature and magnitudes of solute- solute and solute – solvent interactions have been reported in the apparent molar volume (ϕv), slope (S_V), and coefficients of Jones- Dole and modified Jones- Dole equation, adiabatic compressibility (β_{ad}) , limiting apparent molar compressibility, apparent molar compressibility (ϕk), specific acoustic impedance (Z), relative association (RA), The results were supported by the plots.

Key words: - Jones- Dole and modified Jones- Dole equation, Solute- solute and solute - solvent interactions, Sucrose.

I.INTRODUCTION

The wide range of carbohydrate uses has generated significant interest across various industries, including food, pharmaceuticals, and chemicals[1-3]. The interactions between non-ionic solutes and ionic solvents are influenced by physicochemical forces, as detailed in reference [4]. Fluoride has been crucial in advancing oral and dental health for fifty years. In recent years, there have been advancements in our knowledge of dental caries, including their mechanism and the impact of fluoride. It is recommended for children receiving orthodontic treatment or radiotherapy to incorporate fluoride mouthwash into their oral care routine [10-13]. Most biochemical processes take place in a liquid environment. Studying sodium fluoride's thermodynamic and acoustic properties in a ternary system is essential for gaining insights into various interactions within a mixed solvent system. Due to their significance in industrial processes, the density, viscosity, ultrasonic velocity, and related parameters of sodium fluoride and sucrose aqueous solutions were examined at different concentrations and temperatures of 298.15K and 304.15K. Comprehending physiological processes necessitates a comprehensive examination of sucrose. They are crucial in coordinating biological molecules, as referenced in citations [14-15].

II.EXPERIMENTAL

Sodium fluoride with 99.9% purity from Sigma Chemicals underwent a vacuum drying procedure. Sigma Chemicals supplied sucrose with a purity of 99.5%. The chemicals were employed in their original form without undergoing any additional purification. Solutions with different quantities of sucrose were created by dissolving correctly measured sugar in aqueous solutions of sodium fluoride with concentrations of 0.1M, 0.2M, 0.4M, and 0.6M.

All solution densities were measured with a double-armed pycnometer with an 18 cm3 capacity [5]. The pycnometer was calibrated using highly purified water at various temperatures (298.15K, 303.15K, 308.15K and 313.15K)and density levels0.9970, 0.9956, 0.9940 and 0.9922g.cm^{-3}[6]. A clear water bath with precise temperature control$\pm$0.01K was used to house the pycnometer filled with the test liquids, which were kept bubble-free until thermal equilibrium was established after 10–15 minutes. The liquid levels in both arms were measured precisely with a handheld microscope. The solution's density measurements have an estimated margin of error of +0.00005 g.cm^{-3}.

Viscosity was measured with an Ubbelohde viscometer that was commercially available. In previous studies, Lee et al.[7-8] and Nikam et al.[9] have utilized this viscometer. The viscometer was calibrated using triple distilled water with precise viscosities 0.890, 0.797, 0.719, and 0.652mPa.s at various temperaturesat 298.15K, 303.15K, 308.15K and 313.15K [6]. A cleaned and dried viscometer filled with the trial liquid was put vertically in a thermostat. Once thermal equilibrium was reached, the efflux durations for liquid flow were measured using a highly accurate digital stopwatch with a precision of $\pm$0.01 seconds. As all flow durations exceeded 300 seconds, modifications for kinetic energy were not implemented. To determine viscometer constants, adjust the length of the viscometer capillary by adding l'= l + 0.5r times the capillary's radius to compute the corrected length. Due to the significant disparity in length l (50-60mm) and radius r (0.5mm), l is equivalent to l', leading to little end effects in the viscometer. The viscosity measurement had a reproducibility of ± 0.001mPa.s.

The ultrasonic velocity in the prepared solutions (2MHz) was measured using a variable path fixed-frequency ultrasonic interferometer (Mittal-F-05). The sound velocity is accurate to $\pm$ 0.1ms^{-1}.

III.RESULT AND DISCUSSION

All statistical data can be presented in a tabular format. Tables 1 and 2 display sucrose's density, viscosity, and ultrasonic velocity values in sodium fluoride water. Sodium fluoride was selected at concentrations of 0.1M, 0.2M, 0.4M, and 0.6M, while sucrose was tested at values of 0.0249M, 0.0499M, 0.0999M, 0.1999M, and 0.3999M. By adjusting the sucrose and sodium fluoride levels, you can achieve higher densities and viscosities. On the other hand, raising the temperature will lead to decreased values. Density is a technique that analyses the relationships between solvents and ions within a solution. Enhanced focus leads to higher density, leading to more significant interactions between the solvent and solution and between ions and the solution. The volume diminishes because of the existence of solute molecules. One alternative is to expose it through the solvent's structural alteration caused by the solute's introduction [16]. Ultrasonic velocity measurements have increased with higher concentrations and temperature levels. Combining the solvent (aqueous NaF solution) with the solute (sucrose) improves the disruption of the water structure. The behaviour is attributed to the cohesiveness resulting from ionic hydration. The ultrasonic velocity in the prepared solutions (2 MHz) was measured using a variable path fixed-frequency ultrasonic interferometer (Mittal-F-05). The sound velocity is accurate to +0.1 m/s.

The parameters that were examined, such as the limiting apparent molar volume (ϕ^0_v), its associated constant (S_v), and apparent molar volume (ϕ_v), are listed in Tables 3 and 4 according to the Masson equation [17].

$$\phi_v = \phi^0_v + S_v\sqrt{C} \quad \ldots\ldots\ldots\ldots \quad (1)$$

Increasing sucrose content leads to higher apparent molar volume values (ϕ_v). Nonetheless, as the molar concentration of aqueous NaF increases, the same characteristics are shown to decrease. The positive values of the limiting apparent molar volume(ϕ^0_v) decrease as the concentration of sucrose and solvent (aqueous NaF) rises.Sucrose has a positive slope(S_v) at all temperatures in all aqueous NaF solutions. Positive $S_v$values indicate a substantial sucrose connection when ions are present, according to the Debye-Huckel theory. As previously reported, S_v has been used to demonstrate solute-solute interactions [18,19,20 21]. Viscosity values rise with higher solute and solvent concentrations but decrease with increasing temperature.Table 5 displays the values of ɳr-1/√C for sucrose solutions in aqueous NaF at various temperatures, whereas Table 6 lists the values of ɳr at different temperatures.For η_r-1/√C values, Jones -Dole equation is employed [25].

$$\eta_r - 1/\sqrt{C} = A + BC^{1/2} \quad \ldots\ldots\ldots \quad (2)$$

Modified Jones -Dole equationis employed to calculate the values of B.

$\eta_r = 1 + B\,C$ …….. (3)

The positive values of coefficient 'A' in table number -7 [26] indicate the presence of strong ion-ion interactions in the system. The 'B' coefficient determines if the solute molecules have introduced order or disorder into the solvent. Positive values of the 'B' coefficient suggest a robust ion-solvent interaction. The arrangement of sucrose molecules could clarify why the 'B' coefficient shows a positive value, indicating a rise in ion-solvent interactions. These values are listed in Table number -8.

The various acoustical parameters of sucrose in aqueous NaF have been calculated using following relations.

$\phi_K = \phi^o_K + S_K\sqrt{C}$ ……. (4)

Where$S_K$and ϕ^o_K are the slope and intercepts derived from Bacham's equation.

$$\beta_{ad} = \frac{1}{U^2 \times \varrho} \quad \text{…………} \quad (5)$$

$$\phi_k = \frac{1000(\varrho_0\beta_{ad} - \varrho\,\beta^0_{ad})}{C \times \varrho_0} + \frac{\beta^0_{ad} \times M^2}{\varrho_0} \quad \text{………}(6)$$

$$Z = U \times \varrho \text{………} (7)$$

$$R_A = \frac{\varrho}{\varrho_0}\left(\frac{U_0}{U}\right)^{1/3} \text{………} \quad (8)$$

Whereβ_{ad},ϕ^0_k, ϕ_k, Z and RArepresent adiabatic compressibility, limiting apparent molar compressibility, apparent molar compressibility, specific acoustic impedance and relative association respectively.

The variables β_{ad}, ϕ^0_k, ϕ_k, Z and RA represent adiabatic compressibility, limiting apparent molar compressibility, specific acoustic impedance, and relative association, respectively.

As the concentrations of NaF and sucrose increase, along with higher temperatures, the ultrasonic velocity also rises. The change may have occurred because of the disturbance in the water structure caused by the introduction of solvents (aqueous NaF) and solutes (sucrose). Refer to Tables 9 and 10 for the molar compressibility values (ϕk), the limiting molar compressibility values (ϕ^0_k), and their corresponding constants (S_K). The molar compressibility and limiting molar compressibility values show a negative trend as the concentrations of NaF and sucrose increase, along with higher temperatures. When ϕkvalues are negative, it indicates the presence of hydrophilic interactions within the system. Studying apparent molar compressibility (ϕ^0_k) offers valuable insights into ion-solvent interactions and the solution's constant (S_K) ion-ion interactions.

Table 11 shows how β_{ad} decreases with temperature and concentration changes. The OH groups of sucrose interact with the NaF solution via dipole-dipole interactions. The decrease in β_{ad}values is owing to the increased electrostriction compression of the solvent around the molecules, resulting in a significant decline in the compressibility of solutions [27]. Acoustic impedance values(z), as well as temperature, increase when NaF and sugar concentrations rise. This pattern indicates the effective interaction of solute and solvent. Higher concentrations of NaF and sucrose and higher temperatures cause an increase in the factor relative association (RA), indicating substantial ion-solvent interactions[28].

Table 1: Density, ρ / (g.cm^{-3}) and Viscosity,η (mPa.s)for sucrose in aqueous NaF.

Molarity (M) of sucrose	ρ (g.cm^{-3})		η (mPa.s)	
	298.15K	304.15K	298.15K	304.15K
	Sucrose in 0.1M NaF			
0.0249	1.0046	1.0030	1.004	0.860
0.0499	1.0088	1.0075	1.054	0.893
0.0999	1.0166	1.0160	1.135	0.951
0.1999	1.0305	1.0310	1.269	1.048
0.3999	1.0529	1.0552	1.494	1.220
	Sucrose in 0.2M NaF			
0.0249	1.0100	1.0083	1.035	0.883
0.0499	1.0144	1.0131	1.090	0.921
0.0999	1.0227	1.0222	1.178	0.984

0.1999	1.0376	1.0382	1.327	1.093
0.3999	1.0618	1.0645	1.581	1.287
	Sucrose in 0.4M NaF			
0.0249	1.0197	1.0172	1.091	0.926
0.0499	1.0245	1.0224	1.155	0.969
0.0999	1.0335	1.0320	1.256	1.041
0.1999	1.0493	1.0491	1.421	1.162
0.3999	1.0746	1.0769	1.700	1.376
	Sucrose in 0.6M NaF			
0.0249	1.0294	1.0258	1.156	0.973
0.0499	1.0345	1.0313	1.227	1.022
0.0999	1.0442	1.0417	1.340	1.103
0.1999	1.0613	1.0602	1.521	1.238
0.3999	1.0894	1.0905	1.831	1.474

Table 2: Ultrasonic velocity, U/(m/sec)for sucrose in aqueous NaF.

Molarity (M) of sucrose	U (m/sec)			
	298.15K	304.15K	298.15K	304.15K
	Sucrose in 0.1M NaF		**Sucrose in 0.2M NaF**	
0.0249	1512	1526	1521	1535
0.0499	1518	1532	1526	1540
0.0999	1528	1542	1536	1549
0.1999	1545	1559	1551	1565
0.3999	1571	1584	1574	1587
	Sucrose in 0.4M NaF		**Sucrose in 0.6M NaF**	
0.0249	1537	1550	1554	1567
0.0499	1542	1555	1559	1572
0.0999	1551	1564	1567	1580
0.1999	1566	1578	1580	1592
0.3999	1586	1598	1597	1609

Table 3: Values of apparent molar volume (ϕ_v) for sucrose solutions in aqueous NaF at different temperatures.

√C	0.1M NaF	0.2M NaF	0.4M NaF	0.6M NaF	0.1M NaF	0.2M NaF	0.4M NaF	0.6M NaF
	298.15 K				304.15 K			
0.1578	160.42	147.08	134.55	118.16	147.89	134.17	120.04	102.47
0.2236	167.48	155.00	141.44	126.02	153.31	141.04	127.41	110.89
0.3162	176.35	164.48	150.83	135.78	162.85	150.64	137.24	121.66
0.4471	190.22	178.41	166.26	151.49	177.99	165.94	153.19	137.73
0.6324	209.97	199.26	189.30	174.02	199.65	187.94	177.04	162.33

Table 4: The limiting apparent molar volume $\phi^0_v$and $S_v$for sucrose in aqueous NaF at different temperatures.

Temp. K	ϕ^0_v ($cm^3.L^{1/2}Mol^{3/2}$)	S_v (cm^3 mol^{-1})	ϕ^0_v ($cm^3.L^{1/2}$ $Mol^{3/2}$)	S_v (cm^3 mol^{-1})	ϕ^0_v ($cm^3.L^{1/2}$ $Mol^{3/2}$)	S_v (cm^3 mol^{-1})	ϕ^0_v ($cm^3.L^{1/2}$ $Mol^{3/2}$)	S_v (cm^3 mol^{-1})
	Sucrose in 0.1M NaF		Sucrose in 0.2M NaF		Sucrose in 0.4M NaF		Sucrose in 0.6M NaF	
298.15	143.887	104.116	130.121	108.990	115.445	115.464	99.377	117.389

304.15	129.122	110.363	115.591	113.572	100.331	120.047	82.446	125.420

Table 5: Values of η_r-1/√C for sucrose solutions in aqueous NaF at different temperatures.

√C	0.1M NaF	0.2M NaF	0.4M NaF	0.6M NaF	0.1M NaF	0.2M NaF	0.4M NaF	0.6M NaF
	298.15 K				304.15 K			
0.1578	0.6678	0.7284	0.7985	0.8775	0.4647	0.5272	0.5948	0.6813
0.2236	0.7192	0.7823	0.8578	0.9326	0.5156	0.5811	0.6527	0.7340
0.3162	0.7908	0.8519	0.9359	1.0122	0.5920	0.6549	0.7310	0.8120
0.4471	0.8898	0.9611	1.0423	1.1146	0.6900	0.7617	0.8341	0.9171
0.6324	1.0198	1.1128	1.1928	1.2709	0.8272	0.9165	0.9913	1.0730

Table 6: Relative viscositiesη_r for sucrose solutions in aqueous NaF at different temperatures.

C	0.1M NaF	0.2M NaF	0.4M NaF	0.6M NaF	0.1M NaF	0.2M NaF	0.4M NaF	0.6M NaF
	298.15 K				304.15 K			
0.0249	1.1056	1.1152	1.1263	1.1387	1.0735	1.0834	1.0940	1.1077
0.0499	1.1608	1.1749	1.1918	1.2085	1.1153	1.1299	1.1459	1.1641
0.0999	1.2499	1.2693	1.2958	1.3199	1.1871	1.2070	1.2310	1.2566
0.1999	1.3979	1.4298	1.4661	1.4985	1.3086	1.3406	1.3730	1.4101
0.3999	1.6450	1.7038	1.7544	1.8038	1.5232	1.5796	1.6270	1.6786

Table 7: Jones-Dole parameters for sucrose solutions in aqueous NaF at different temperatures.

Temp. K	A ($dm^{3/2}$ $mol^{-1/2}$)	B (dm^3 mol^{-1})	A ($dm^{3/2}$ $mol^{-1/2}$)	B (dm^3 mol^{-1})	A ($dm^{3/2}$ $mol^{-1/2}$)	B (dm^3 mol^{-1})	A ($dm^{3/2}$ $mol^{-1/2}$)	B (dm^3 mol^{-1})
	Sucrose in 0.1M NaF		Sucrose in 0.2M NaF		Sucrose in 0.4M NaF		Sucrose in 0.6M NaF	
298.15	0.5537	0.7424	0.5996	0.8095	0.6716	0.8270	0.7482	0.8256
304.15	0.3464	0.7641	0.3973	0.8190	0.4658	0.8300	0.5504	0.8248

Table 8: Modified Jones-Dole parameterB for sucrose solutions in aqueous NaF at different temperatures.

Temperature K	β/ (dm^3 mol^{-1})			
	Sucrose in 0.1M NaF	Sucrose in 0.2M NaF	Sucrose in 0.4M NaF	Sucrose in 0.6M NaF
298.15	1.4147	1.5443	1.6449	1.7401
304.15	1.1840	1.3062	1.3993	1.4986

Table 9: Apparent molar compressibility (ϕ_K) for sucrose solutions in aqueous NaF at different temperatures.

√C	0.1M NaF	0.2M NaF	0.4M NaF	0.6M NaF	0.1M NaF	0.2M NaF	0.4M NaF	0.6M NaF
	298.15 K, ϕ_K (cm^2/dyne)				304.15 K, ϕ_K (cm^2/dyne)			
0.1578	-165.23	-152.05	-142.50	-131.81	-161.47	-149.68	-139.40	-129.46
0.2236	-157.51	-145.58	-135.81	-125.33	-154.24	-143.31	-132.93	-123.15
0.3162	-146.81	-135.61	-125.61	-115.24	-143.53	-133.28	-122.52	-113.12

0.4471	-130.06	-119.27	-110.54	-100.10	-127.26	-118.27	-107.89	-97.48
0.6324	-107.87	-97.08	-87.78	-77.49	-105.22	-95.58	-85.18	-75.19

Table 10: Limiting apparent molar compressibility (ϕ^0_K), S_k for sucrose solutions in aqueousNaF at different temperatures.

Temp. K	ϕ^0_K(cm^3/mol)	S_k	ϕ^0_K (cm^3/mol)	S_k	ϕ^0_K (cm^3/mol)	S_k	ϕ^0_K (cm^3/mol)	S_k
	Sucrose in 0.1M NaF		Sucrose in 0.2M NaF		Sucrose in 0.4M NaF		Sucrose in 0.6M NaF	
298.15	-184.620	121.370	-171.470	116.920	-161.520	115.580	-150.830	114.930
304.15	-180.700	119.190	-168.700	114.470	-158.280	114.520	-148.620	115.230

Table 11: Adiabatic compressibility β_{ad}(cm^2/dyne), acoustical impedance(Z), relative association (RA)at different temperaturues.

Molarity (M) of sucrose	β_{ad} x10^{12}	z x 10^{-5}	RA	β_{ad} x10^{12}	z x 10^{-5}	RA	β_{ad} x10^{12}	z x 10^{-5}	RA	β_{ad} x10^{12}	z x 10^{-5}	RA
	Sucrose in 0.1 M NaF			Sucrose in 0.2 M NaF			Sucrose in 0.4 M NaF			Sucrose in 0.6 M NaF		
	298.15 K											
0.0249	43.931	1.519	1.003	43.669	1.536	1.007	43.139	1.567	1.013	42.621	1.599	1.019
0.0499	43.785	1.531	1.006	43.558	1.548	1.010	43.063	1.579	1.016	42.580	1.612	1.023
0.0999	43.535	1.553	1.012	43.373	1.570	1.016	42.946	1.602	1.023	42.531	1.636	1.030
0.1999	43.158	1.592	1.022	43.125	1.609	1.027	42.792	1.643	1.036	42.511	1.676	1.044
0.3999	42.662	1.654	1.038	42.866	1.671	1.046	42.730	1.704	1.056	42.715	1.739	1.068
	304.15 K											
0.0249	43.061	1.530	1.004	42.807	1.547	1.007	42.318	1.576	1.013	41.773	1.607	1.018
0.0499	42.942	1.543	1.007	42.719	1.560	1.011	42.264	1.589	1.017	41.753	1.621	1.022
0.0999	42.738	1.566	1.013	42.578	1.583	1.018	42.191	1.614	1.024	41.743	1.645	1.031
0.1999	42.434	1.607	1.024	42.379	1.624	1.030	42.112	1.655	1.038	41.807	1.687	1.046
0.3999	42.056	1.671	1.043	42.224	1.689	1.051	42.188	1.720	1.061	42.122	1.754	1.072

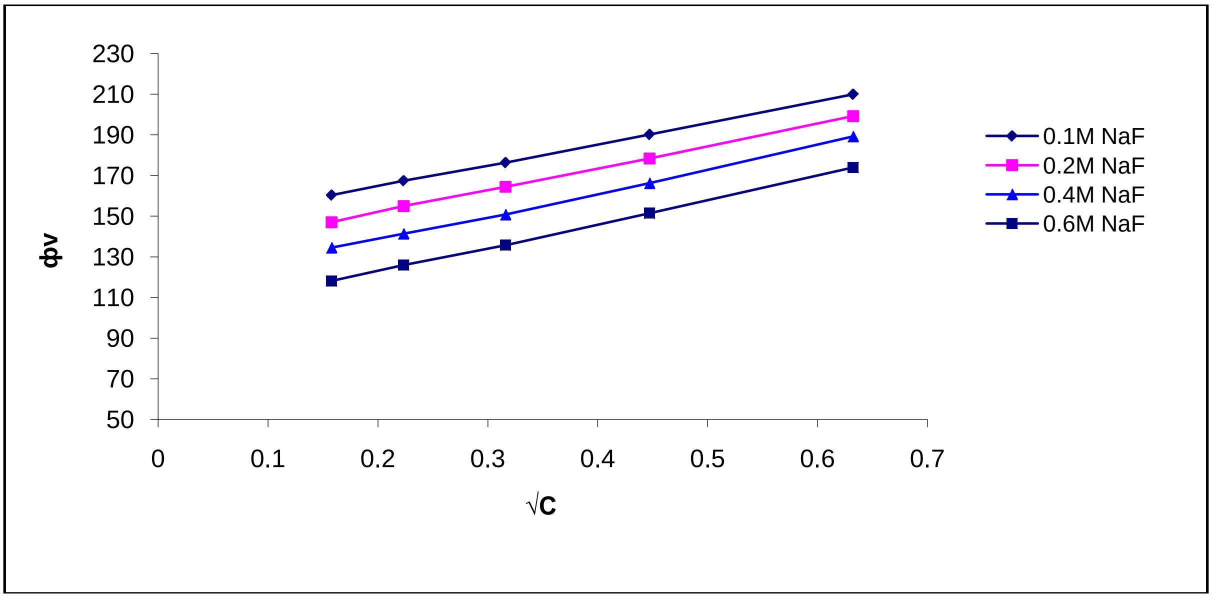

Fig.1 Plot of φvVs√C of sucrose in aqueous NaF at 298.15K

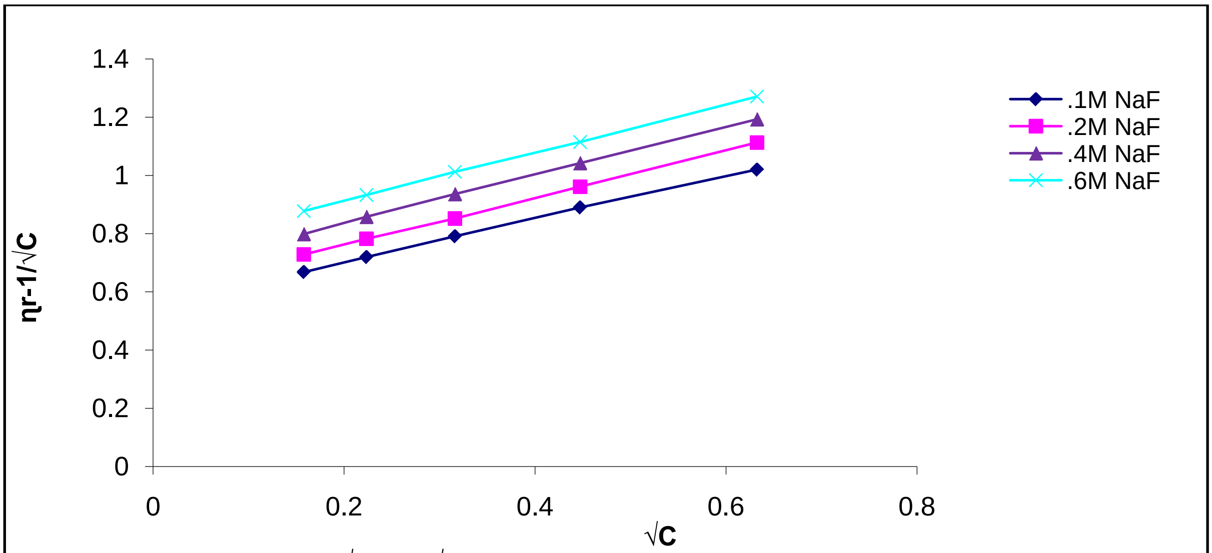

Fig 2. Plot of ηr-1/√C Vs √C of Sucrose in water and in aqueous NaF at 298.15K

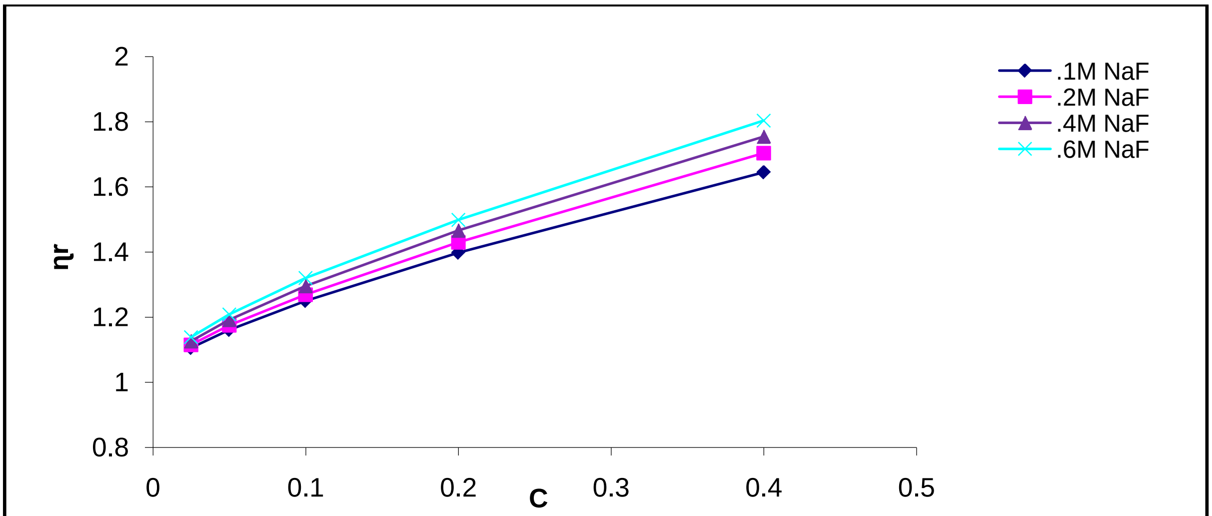

Fig.3 Plot of ηrVs C of Sucrose in water and in aqueous NaF at 298.15K

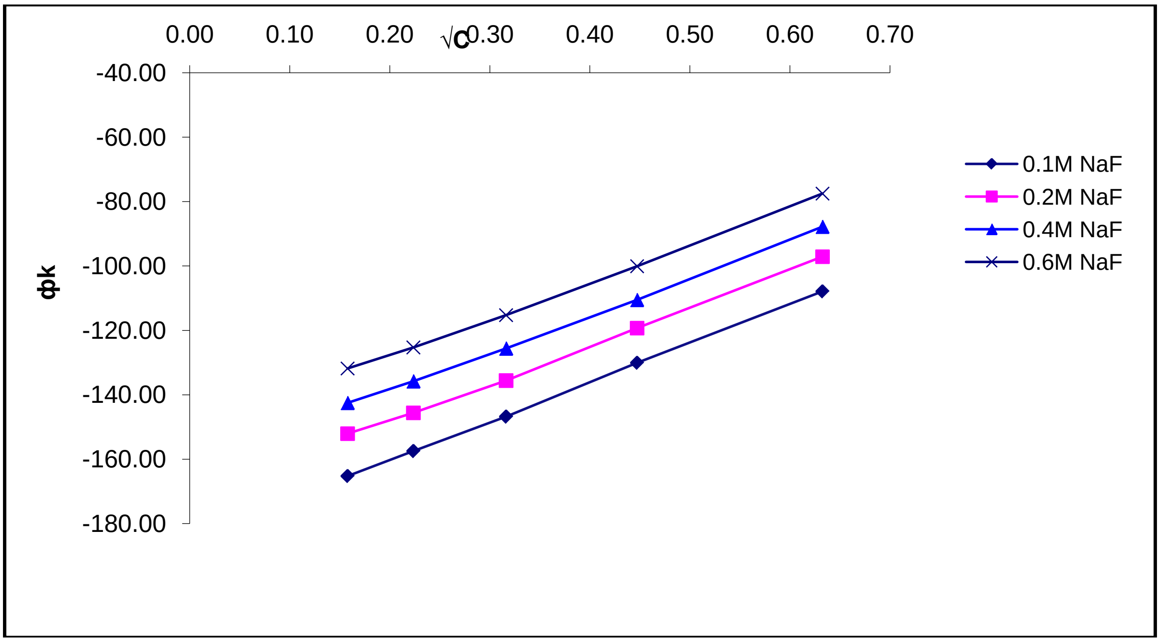

Fig.4 plot of ϕk vs √C of sucrose in aqueous NaF at 298.15K

IV.CONCLUSION

In the current research, density, viscosity, and ultrasonic velocity measurements were taken at 298.15K and 304.15K for the NaF and sucrose systems. Various parameters such as molar volume(ϕ_v), slope(S_V), coefficients A and B of the Jones-Dole equation, adiabatic compressibility(β_{ad}), apparent molar compressibility (ϕ_k), limiting apparent molar compressibility ($\phi^0{}_k$), specific acoustic impedance(Z) and relative association (RA) were calculated to analyze the molecular interactions in the system. The investigated system shows significant interactions among solute-solute, solute-solvent, and solvent-solvent components. It gets better when concentrated but decreases with temperature.

Acknowledgement: -Authors are very much thankful to the Head, department of Chemistry and the Principal, LVH College, Panchavati, Nashik for providing laboratory and library facilities.

Conflict of Interest: -Authors declare no conflict of interest.

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