Letters in Applied NanoBioScience
Open-Access Journal (ISSN: 2284-6808)

Article
Volume 12, Issue 4, 2023, 171
https://doi.org/10.33263/LIANBS124.171

Thermodynamic and Acoustic Studies of Glycols in Aqueous Solutions of Niacin

Prachi Patnaik [1], Nabaparna Chakraborty [1], K.C. Juglan [1,*], Harsh Kumar [2,*]

[1] Department of Physics, Lovely Professional University, Phagwara, 144401, Punjab, India
[2] Department of Chemistry, Dr. B R Ambedkar NIT, Jalandhar 144 011, Punjab, India
* Correspondence: kc.juglan@lpu.co.in(K.C.J), h.786.man@gmail.com (H. K);
Scopus Author ID 55955417800 (K.C.J.)
55363475800 (H.K.)

Received: 25.01.2022; Accepted: 12.03.2022; Published: 28.12.2022

Abstract: The densities and speed of sound for liquid mixtures including Ethylene glycol (EG)/Diethylene glycol (DEG)/Triethylene glycol (TEG) in aqueous vitamin B_3 (niacin) at (0.02, 0.04, and 0.06) mol·kg^{-1} concentration is measured at the temperature variation from (293.15 to 308.15) K with Anton Paar DSA 5000 M. Various acoustic and thermodynamic parameters such as intermolecular free length, acoustic impedance, adiabatic compressibility, Wada's constant, Rao's Constant and Vander Waal's constant were calculated using experimental data which helped to understand the intermolecular reactions inside the ternary mixture of vitamin B_3 (Niacin) and glycols (EG, DEG and TEG).

Keywords: niacin; vitamin B_3; glycols; thermodynamic parameters; acoustic parameters.

1. Introduction

Over the past few years, using ultrasonic technique, the study of volumetric, acoustical, physicochemical, and thermodynamic properties of liquid mixtures has substantiated exponential growth. This technique has been a huge source of information about the molecular interactions taking place inside a liquid system and is highly preferred over other methods as it is a non-destructive technique (i.e., it doesn't cause any distortion to the shape and structure of the specimen) [1]. Analyzing the molecular behavior of liquids is one of the essential branches of Physics. A hefty amount of theoretical and experimental work regarding various combinations of liquid mixtures has been done, and several research studies have been executed to verify these theories to induce whole information about the forces possessed by the accumulation of molecules [2,3].

The volumetric characteristics provide information on mixture-solving techniques as well as system packaging. Studies demonstrate how sensitive volumetric properties are to solute-solvent interactions. Surveys of volumetric properties within the temperature range are crucial since these properties help to comprehend the various system processes.

Data on the structural effects of solutes on water structure can occasionally be found by observing how temperature affects the behavior of volumetric features of mixes in water. It is proposed that the temperature dependence limiting partial molar volume provides solute hydration and equilibrium between hydrophobic and hydrophilic interactions between solute and water at infinite dilution.

The organic compound niacin, also known as nicotinic acid, is one of the eight water-soluble B vitamins and is a form of vitamin B3, a key human nutrient. It is used as a dietary supplement to treat pellagra and nonmelanoma skin cancer and lower cholesterol. Niacin is first- or second-line therapy for all 5 treatable lipid metabolism disorders [4-9].

In view of various synthetic methodologies of EG, DEG, and TEG in modern technology and conventional industries, great efforts have been undertaken to improve synthetic processes, enhance catalytic performance, and reduce investment costs. At present, the technology of hydration of ethylene oxidation accounts for the major market share [10].

Nabaparna *et al*. have investigated various acoustic and volumetric properties of the mixture (Niacin+ water + Ethylene glycol (EG)/Diethylene glycol (DEG)/Triethylene glycol (TEG)) were measured at atmospheric pressure and (0.02, 0.04 and 0.06) $mol \cdot kg^{-1}$ niacin concentrations at different temperatures through the calculated parameters, i.e., Apparent Molar Volume, Partial Molar Volume and Partial Molar Volume of transfer, which are determined from the experimental density values and Apparent Molar Isentropic compression, Partial Molar Isentropic compression and Partial Molar Isentropic compression of transfer are calculated using the speed of sound [11-13].

Using the data from this investigation, the current study is done to obtain various acoustic and thermodynamic parameters such as intermolecular free length, acoustic impedance, adiabatic compressibility, Wada's constant, Rao's Constant, and Vander Waal's constant regarding the interaction in the liquid system of niacin and glycol [14-16].

In cosmetics and pharmaceutical products, vitamins and glycols are widely used; thus, this study provides an important insight into the intermolecular interactions among their molecules and the scope of further property enhancement of the various products[17-19].

The intermolecular free length is a crucial physical property of liquid mixtures, influencing the sound velocity. As temperature decreases, the intermolecular free length decreases, and as a result, the close packing of molecules decreases as well the sound velocity. But the isentropic compressibility decreases with the increase in velocity, which explains the structure-making and breaking of components in binary mixtures. These derived parameters present an accessible method for studying the thermodynamic properties of liquid mixtures not easily obtained by other means[19,20].

2. Materials and Methods

EG, DEG, TEG, and biologically active vitamin B_3 (niacin) have been obtained with a mass fraction purity greater than 0.99. The chemicals were kept in a desiccator over P_2O_5 after being vacuum dried for two days to decrease moisture absorption before their use. To ensure the faster drying at low humidity and pressure, vacuum drying is done where the pressure is kept at 0.03–0.06 atm and the boiling point of water at T=298 to 303 K.

3. Results and Discussion

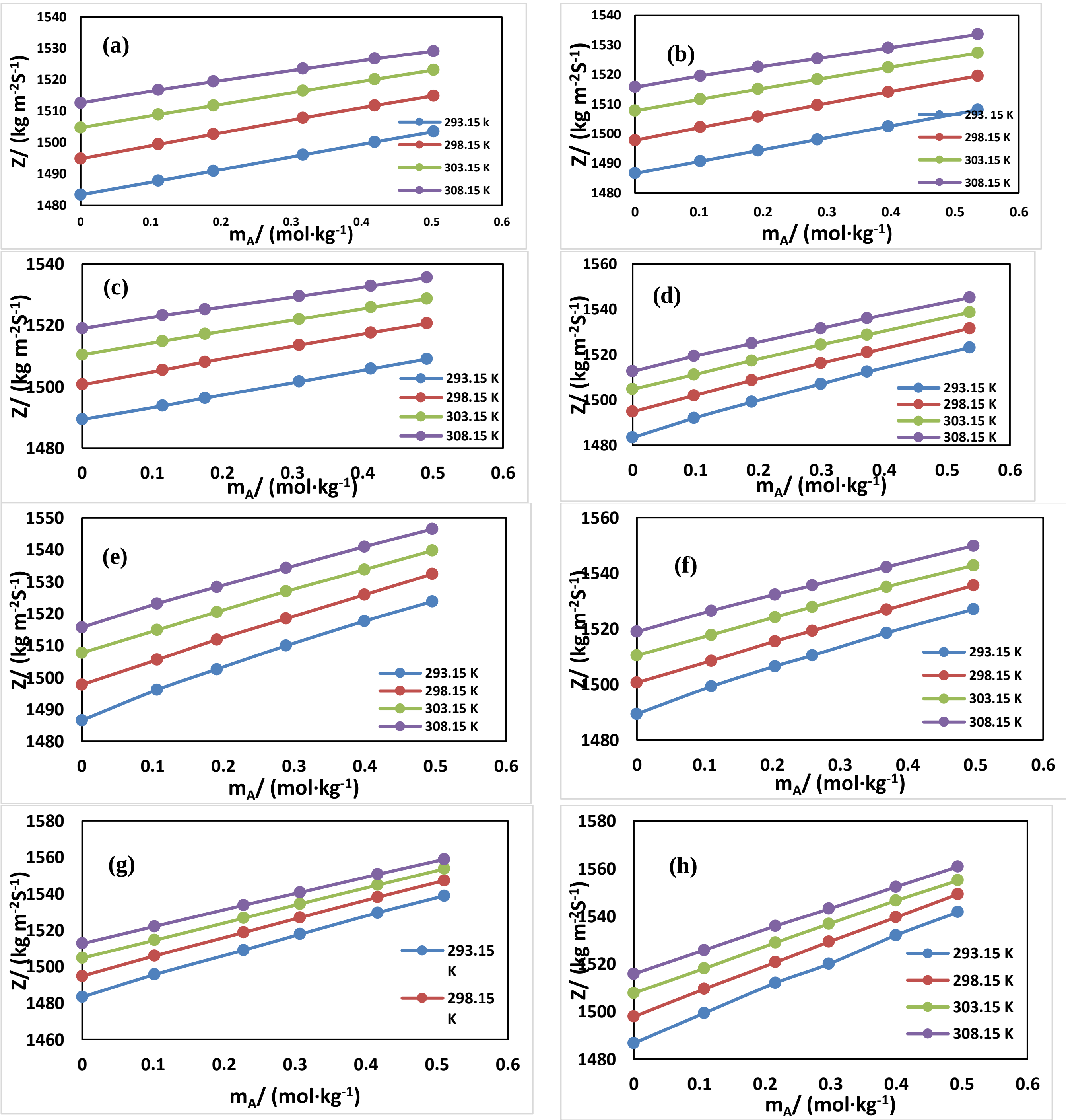
The acoustical parameters calculated in this study from basic parameters U and ρ are intermolecular free length, acoustic impedance, adiabatic compressibility, Wada's constant, Rao's Constant, and Vander Waal's constant. The experimental results for niacin at concentrations of 0.00, 0.02, 0.04, and 0.06 mol.kg-1 with distilled water plus glycols (EG/DEG/TEG) at temperatures ranging from 293.15 K to 308.15 K are presented in Tables 1, 2, and 3.

3.1. Acoustic impedance (Z).

The acoustic impedance is the product of the velocity of ultrasound in a medium and its density and can be calculated by the relation is

$$Z = U\rho \qquad \textit{Equation 1}$$

The impedance values are indexed in **Table 1** and are graphically represented in **Figure 1**. These values grow with molality and temperature, suggesting that no complex interaction occurs inside the liquid mixture.



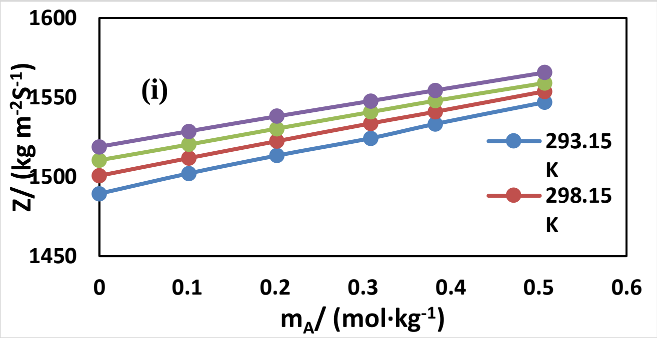


Figure 1. Variation of Acoustic Impedance, Z, of, EG **(a)** 0.02 Niacin, **(b)** 0.04 Niacin and **(c)** 0.06 Niacin; DEG **(d)** 0.02 Niacin, **(e)** 0.02 Niacin, **(f)** 0.04 Niacin; and TEG **(g)** 0.02 Niacin, **(h)** 0.02 Niacin, **(i)** 0.04 Niacin in different concentration of aqueous niacin solutions at different temperatures.

Table 1. Values of Acoustic Impedance, Z and Adiabatic Compressibility, β of PEG 200 and PEG 400 in an aqueous solution of D-Panthenol at different temperatures.

Molality (mol/kg)		**Z(kg m^{-2} s^{-1})**			**β.10^{-7} (N m^{-2})**			
	293.15K	298.15K	303.15K	308.15K	298.15K	303.15K	308.15K	293.15K
EG+0.02 mol kg^{-1} Niacin								
0	1483.3300	1494.8192	1504.7180	1512.5782	4.54	4.47	4.40	4.34
0.1107	1487.7405	1499.3783	1508.9238	1516.7275	4.52	4.44	4.37	4.32
0.1893	1490.9089	1502.6227	1511.7276	1519.3890	4.50	4.43	4.36	4.31
0.3166	1496.0495	1507.8125	1516.4325	1523.4385	4.47	4.40	4.34	4.29
0.4187	1500.1365	1511.7611	1520.1243	1526.6879	4.45	4.38	4.32	4.28
0.5025	1503.4013	1514.8558	1523.0914	1529.0961	4.44	4.37	4.31	4.27
EG+0.04 mol kg^{-1} Niacin								
0	1486.6000	1497.7654	1507.7272	1515.7237	4.52	4.45	4.39	4.33
0.1022	1490.6958	1502.1087	1511.6162	1519.5558	4.5	4.43	4.37	4.31
0.1926	1494.3169	1505.7914	1515.0582	1522.5412	4.49	4.41	4.35	4.30
0.2853	1498.0420	1509.6630	1518.3884	1525.4141	4.47	4.39	4.33	4.28
0.3957	1502.4522	1514.1205	1522.3892	1528.9571	4.44	4.37	4.32	4.27
0.5359	1508.0719	1519.5731	1527.2543	1533.5486	4.42	4.34	4.29	4.24
EG+0.06 mol kg^{-1} Niacin								
0	1489.3690	1500.6643	1510.4337	1518.9345	4.51	4.44	4.37	4.32
0.1148	1493.7882	1505.4320	1514.8622	1523.1916	4.49	4.41	4.35	4.30
0.1748	1496.3230	1508.0410	1517.1284	1525.1454	4.48	4.40	4.34	4.29
0.3093	1501.6180	1513.5703	1522.0173	1529.4478	4.45	4.37	4.32	4.27
0.4115	1505.7979	1517.6110	1525.8004	1532.8030	4.43	4.35	4.30	4.25
0.4915	1508.9936	1520.5654	1528.6267	1535.4850	4.41	4.34	4.29	4.24
DEG+0.02 mol kg^{-1} Niacin								
0	1483.3300	1494.8192	1504.7180	1512.5782	4.54	4.47	4.40	4.35
0.0979	1492.0264	1501.9674	1511.1316	1519.2670	4.49	4.43	4.37	4.32
0.1896	1499.0441	1508.6183	1517.3443	1524.8717	4.46	4.40	4.34	4.29
0.2993	1507.0473	1516.1544	1524.3419	1531.5296	4.42	4.36	4.30	4.26
0.3731	1512.3754	1520.9257	1528.7017	1535.9778	4.39	4.33	4.28	4.24
0.5358	1523.0894	1531.5432	1538.6480	1545.0676	4.34	4.28	4.24	4.19
DEG+0.04 mol kg^{-1} Niacin								
0	1486.6000	1497.7654	1507.7272	1515.7237	4.52	4.45	4.39	4.33
0.1064	1496.1707	1505.5710	1514.8825	1523.1394	4.47	4.41	4.35	4.30
0.1906	1502.6013	1511.8629	1520.5198	1528.3520	4.44	4.38	4.32	4.27
0.2888	1509.9558	1518.4622	1526.9797	1534.2867	4.40	4.35	4.29	4.25
0.3994	1517.6613	1525.9128	1533.7891	1540.9702	4.36	4.31	4.26	4.21
0.4957	1523.8259	1532.4240	1539.7409	1546.5092	4.33	4.28	4.23	4.19
DEG+0.06 mol kg^{-1} Niacin								
0	1489.3690	1500.6643	1510.4337	1518.9345	4.51	4.44	4.37	4.32
0.1098	1499.2493	1508.5070	1517.8255	1526.4723	4.46	4.40	4.34	4.28
0.2041	1506.5537	1515.5571	1524.2358	1532.3582	4.42	4.36	4.31	4.25
0.2594	1510.4468	1519.3235	1527.8751	1535.5853	4.40	4.34	4.29	4.24
0.3688	1518.5568	1526.8921	1535.0878	1542.2715	4.36	4.31	4.25	4.21
0.4976	1527.0570	1535.6249	1542.8457	1549.9034	4.32	4.27	4.22	4.17
TEG+0.02 mol kg^{-1} Niacin								
0.0000	1483.33	1494.82	1504.72	1512.58	4.54	4.47	4.40	4.35
0.1018	1495.62	1505.87	1514.42	1522.05	4.48	4.41	4.35	4.30
0.2273	1508.99	1518.65	1526.54	1533.63	4.41	4.35	4.30	4.25

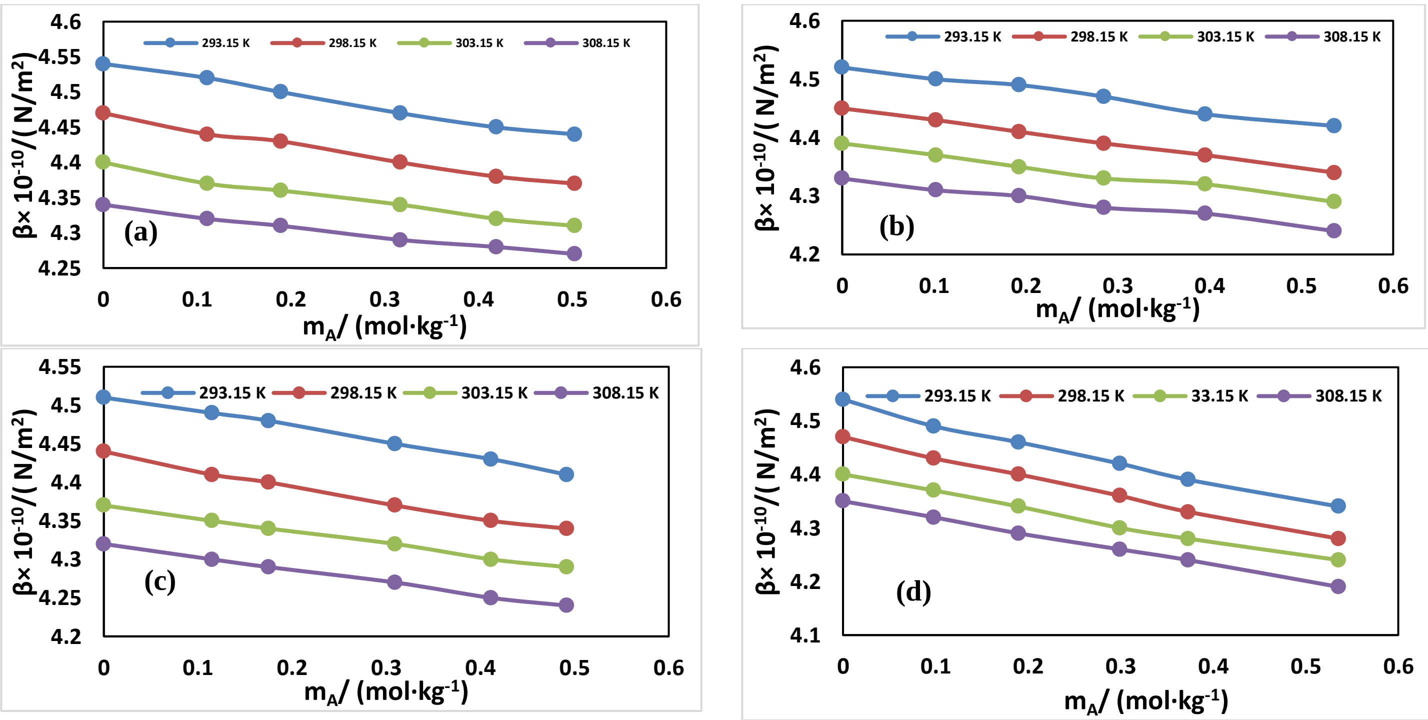
Molality (mol/kg)		Z(kg m^{-2} s^{-1})			β.10^{-7} (N m^{-2})			
0.3071	1517.73	1526.93	1534.39	1540.65	4.36	4.31	4.26	4.22
0.4162	1529.49	1538.02	1544.71	1550.52	4.31	4.25	4.21	4.17
0.5103	1538.81	1547.20	1553.53	1558.80	4.26	4.21	4.17	4.13
TEG+0.04 mol kg^{-1} Niacin								
0	1486.60	1497.77	1507.73	1515.72	4.52	4.45	4.39	4.33
0.1072	1499.26	1509.36	1517.98	1525.73	4.46	4.39	4.34	4.29
0.2161	1511.96	1520.61	1528.89	1535.88	4.39	4.34	4.29	4.24
0.2976	1519.95	1529.23	1536.79	1543.06	4.36	4.30	4.25	4.21
0.3993	1531.97	1539.49	1546.49	1552.31	4.30	4.25	4.20	4.16
0.4943	1541.73	1549.29	1555.01	1560.81	4.25	4.20	4.16	4.13
TEG+0.06 mol kg^{-1} Niacin								
0	1489.37	1500.66	1510.43	1518.93	4.51	4.44	4.37	4.32
0.1019	1502.13	1511.76	1520.30	1528.66	4.45	4.38	4.33	4.27
0.2024	1513.37	1522.44	1530.34	1538.07	4.39	4.33	4.28	4.23
0.3091	1524.30	1533.62	1540.77	1547.74	4.34	4.28	4.23	4.18
0.3826	1533.29	1540.95	1547.87	1554.42	4.29	4.24	4.20	4.15
0.5067	1546.90	1553.76	1559.01	1565.61	4.22	4.18	4.15	4.10

3.2. Adiabatic compressibility (β).

Adiabatic compressibility values were calculated from the speed of sound (u) and the density of the medium (ρ) using Newton and Laplace equation as

$$\beta = \frac{1}{U^2\beta} \qquad \textit{Equation 2}$$

The adiabatic compressibility values are indexed in **Table 1** and are graphically represented in **Figure 2**.



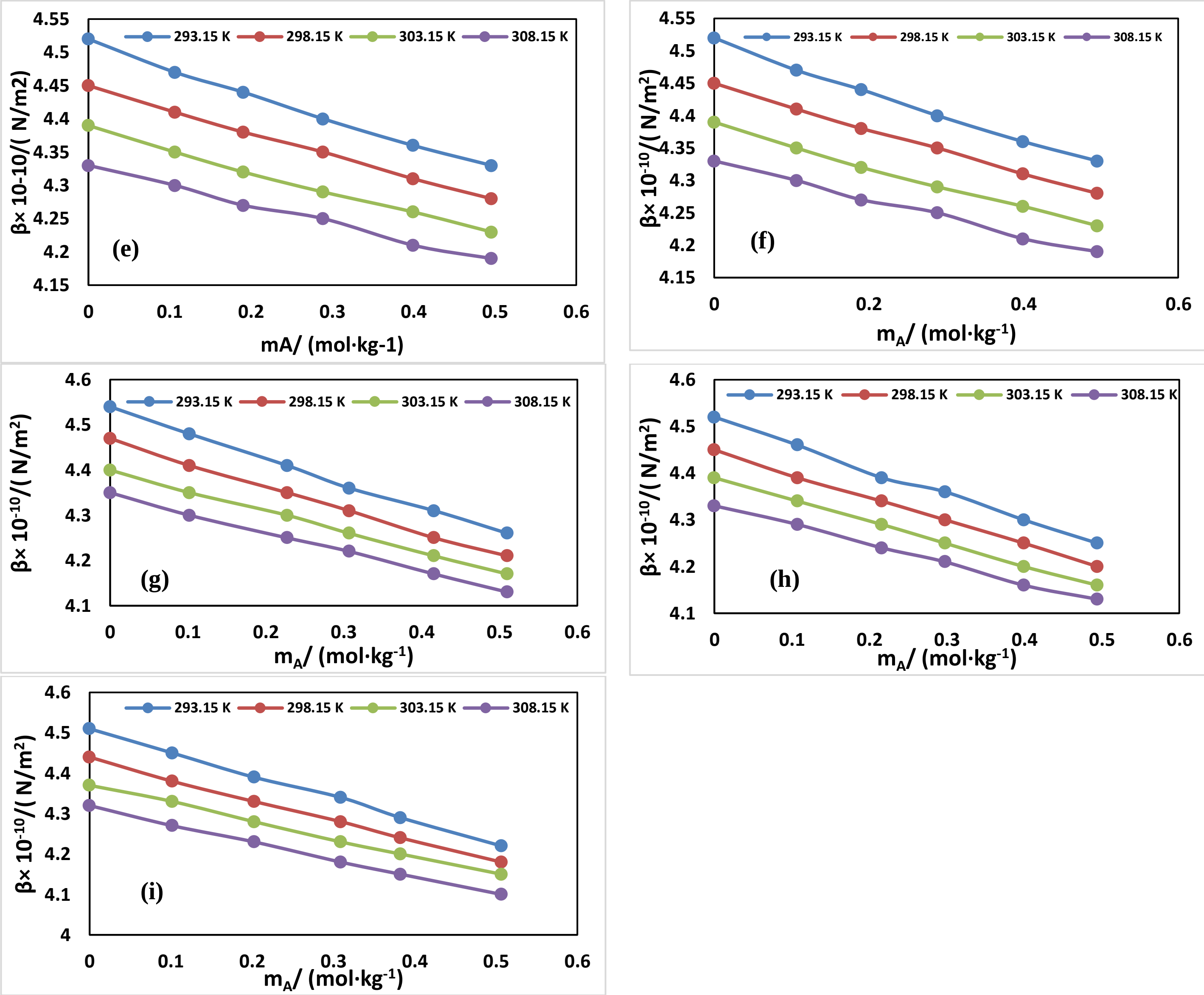


Figure 2. Variation of Adiabatic Compressibility, β, of, EG **(a)** 0.02 Niacin, **(b)** 0.04 Niacin and **(c)** 0.06 Niacin; DEG **(d)** 0.02 Niacin, **(e)** 0.02 Niacin, **(f)** 0.04 Niacin; and TEG **(g)** 0.02 Niacin, **(h)** 0.02 Niacin, **(i)** 0.04 Niacin in different concentration of aqueous niacin solutions at different temperatures.

3.3. Intermolecular free length (Lf).

Semi-empirical relation to achieving the concept of intermolecular free length to explain the ultrasonic velocity in liquids as

$$L_f = K_T\sqrt{\beta} \qquad \textit{Equation 3}$$

The intermolecular free-length values are indexed in **Table 2** and are graphically represented in **Figure 3**.

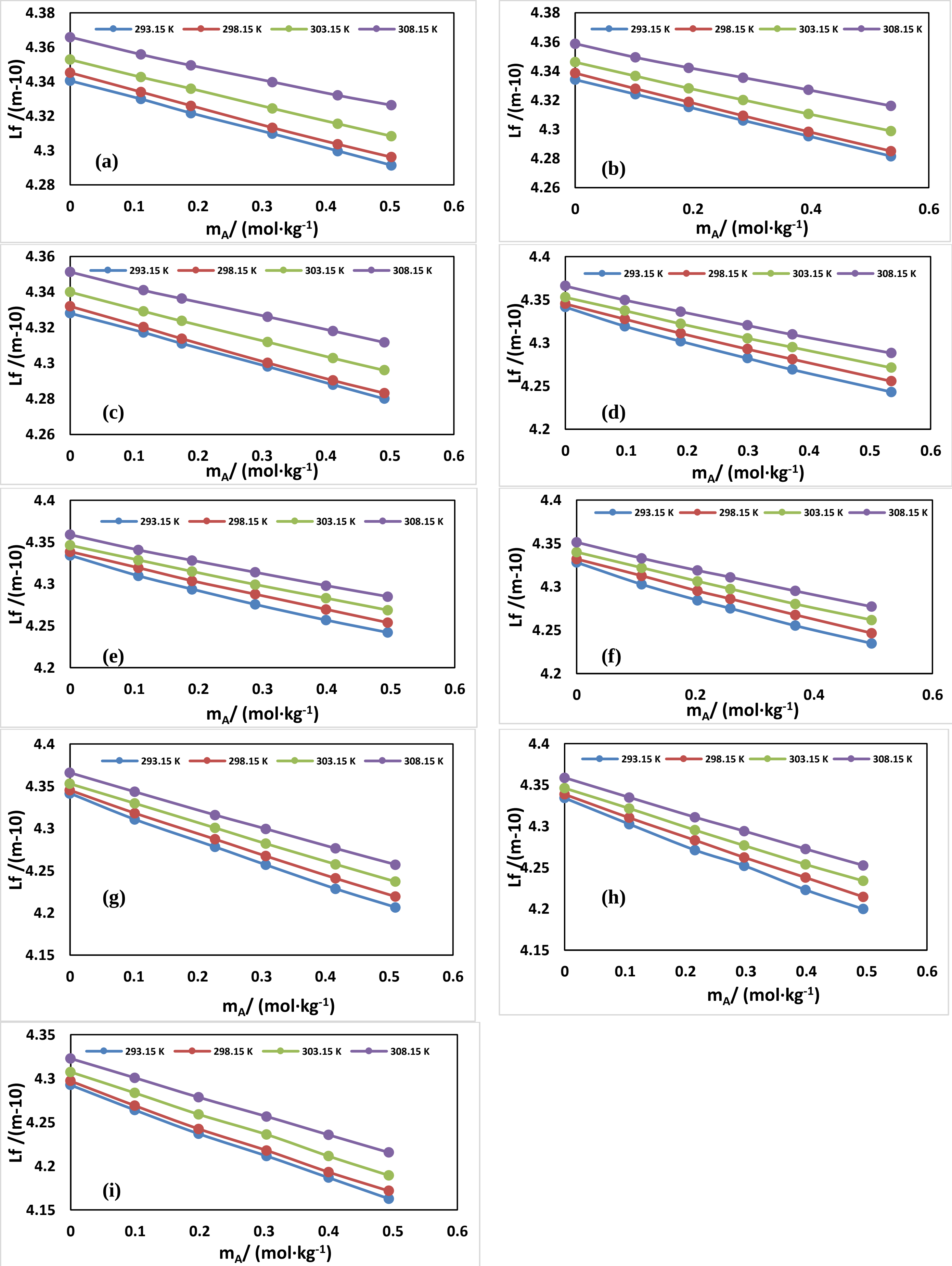


Figure 3. Variation of Intermolecular Free length, L_f, of, EG **(a)** 0.02 Niacin, **(b)** 0.04 Niacin and **(c)** 0.06 Niacin; DEG **(d)** 0.02 Niacin, **(e)** 0.02 Niacin, **(f)** 0.04 Niacin; and TEG **(g)** 0.02 Niacin, **(h)** 0.02 Niacin, **(i)** 0.04 Niacin in different concentration of aqueous niacin solutions at different temperatures.

Table 2. Values of Intermolecular Free Length, Lf of glycols in an aqueous solution of niacin at different temperatures.

Molality (mol/kg)	**Intermolecular Free Length (Lf)**			
	293.15K	298.15K	303.15K	308.15K
EG+0.02 mol kg^{-1} Niacin				
0.0000	4.3405	4.3452	4.3528	4.3659
0.1107	4.3299	4.3340	4.3426	4.3558
0.1893	4.3217	4.3260	4.3359	4.3494
0.3166	4.3097	4.3132	4.3244	4.3398
0.4187	4.2997	4.3036	4.3155	4.3320
0.5025	4.2914	4.2961	4.3083	4.3263
EG+0.04 mol kg^{-1} Niacin				
0.0000	4.3341	4.3386	4.3461	4.3588
0.1022	4.3241	4.3279	4.3366	4.3494
0.1926	4.3153	4.3188	4.3282	4.3423
0.2853	4.3061	4.3093	4.3202	4.3355
0.3957	4.2954	4.2984	4.3106	4.3271
0.5359	4.2816	4.2851	4.2989	4.3161
EG+0.06 mol kg^{-1} Niacin				
0.0000	4.3281	4.3320	4.3400	4.3513
0.1148	4.3173	4.3202	4.3292	4.3410
0.1748	4.3111	4.3138	4.3237	4.3363
0.3093	4.2981	4.3002	4.3119	4.3261
0.4115	4.2879	4.2903	4.3028	4.3181
0.4915	4.2800	4.2832	4.2960	4.3117
DEG+0.02 mol kg^{-1} Niacin				
0.0000	4.3415	4.3452	4.3528	4.3659
0.0979	4.3193	4.3275	4.3373	4.3496
0.1896	4.3018	4.3111	4.3221	4.3362
0.2993	4.2821	4.2927	4.3053	4.3202
0.3731	4.2690	4.2811	4.2949	4.3096
0.5358	4.2431	4.2555	4.2711	4.2881
DEG+0.04 mol kg^{-1} Niacin				
0.0000	4.3341	4.3386	4.3461	4.3588
0.1064	4.3097	4.3193	4.3286	4.3406
0.1906	4.2937	4.3037	4.3149	4.3281
0.2888	4.2755	4.2877	4.2993	4.3139
0.3994	4.2568	4.2696	4.2830	4.2980
0.4957	4.2420	4.2538	4.2687	4.2849
DEG+0.06 mol kg^{-1} Niacin				
0.0000	4.3281	4.3320	4.3400	4.3513
0.1098	4.3028	4.3127	4.3220	4.3329
0.2041	4.2846	4.2952	4.3064	4.3188
0.2594	4.2751	4.2861	4.2976	4.3111
0.3688	4.2552	4.2677	4.2802	4.2952
0.4976	4.2348	4.2466	4.2618	4.2771
TEG+0.02 mol kg^{-1} Niacin				
0.0000	4.3415	4.3452	4.3528	4.3659
0.1018	4.3106	4.3180	4.3296	4.3433
0.2273	4.2781	4.2872	4.3006	4.3159
0.3071	4.2568	4.2672	4.2819	4.2994
0.4162	4.2285	4.2408	4.2575	4.2763
0.5103	4.2066	4.2192	4.2369	4.2571
TEG+0.04 mol kg^{-1} Niacin				
0.0000	4.3341	4.3386	4.3461	4.3588
0.1072	4.3025	4.3102	4.3215	4.3349
0.2161	4.2711	4.2830	4.2953	4.3109
0.2976	4.2521	4.2622	4.2766	4.2941
0.3993	4.2229	4.2378	4.2537	4.2724
0.4943	4.1998	4.2146	4.2339	4.2527
TEG+0.06 mol kg^{-1} Niacin				
0.0000	4.2924	4.2970	4.3073	4.3227
0.0997	4.2639	4.2689	4.2834	4.3007
0.1990	4.2367	4.2423	4.2589	4.2784
0.3044	4.2114	4.2177	4.2359	

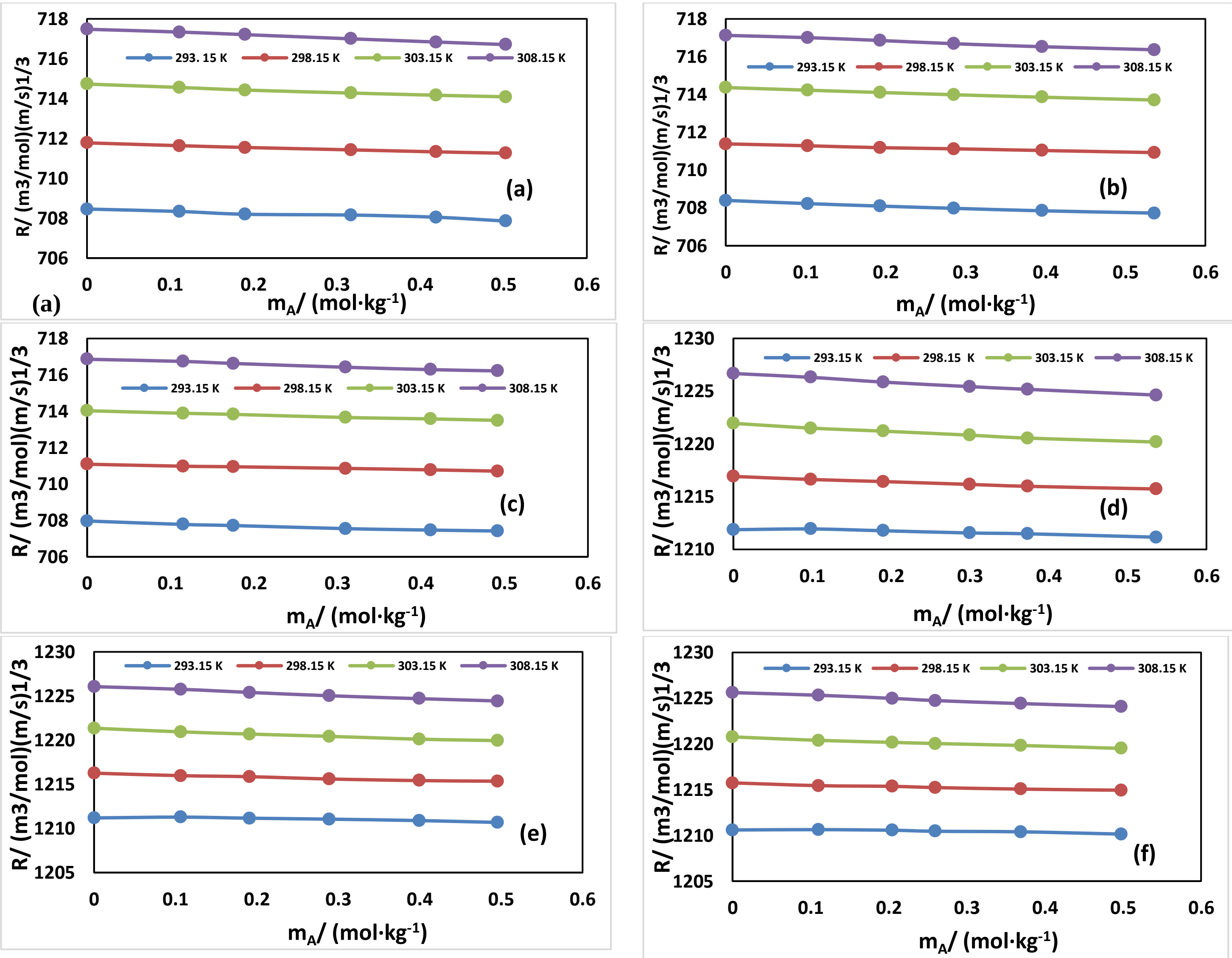
Molality (mol/kg)	Intermolecular Free Length (Lf)			
				4.2565
0.4006	4.1866	4.1930	4.2112	4.2355
0.4937	4.1627	4.1716	4.1893	4.2155

3.4. Rao's constant(R).

Rao proposed that the expansion coefficient, V, and the temperature coefficient, u, are constant for all. Rao gave the equation,

$$R = \frac{U^{\frac{1}{3}}M}{\rho} \qquad \textit{Equation 4}$$

The Rao’s constants are in dexed in **Table 3** and are graphically represented in **Figure 4.**



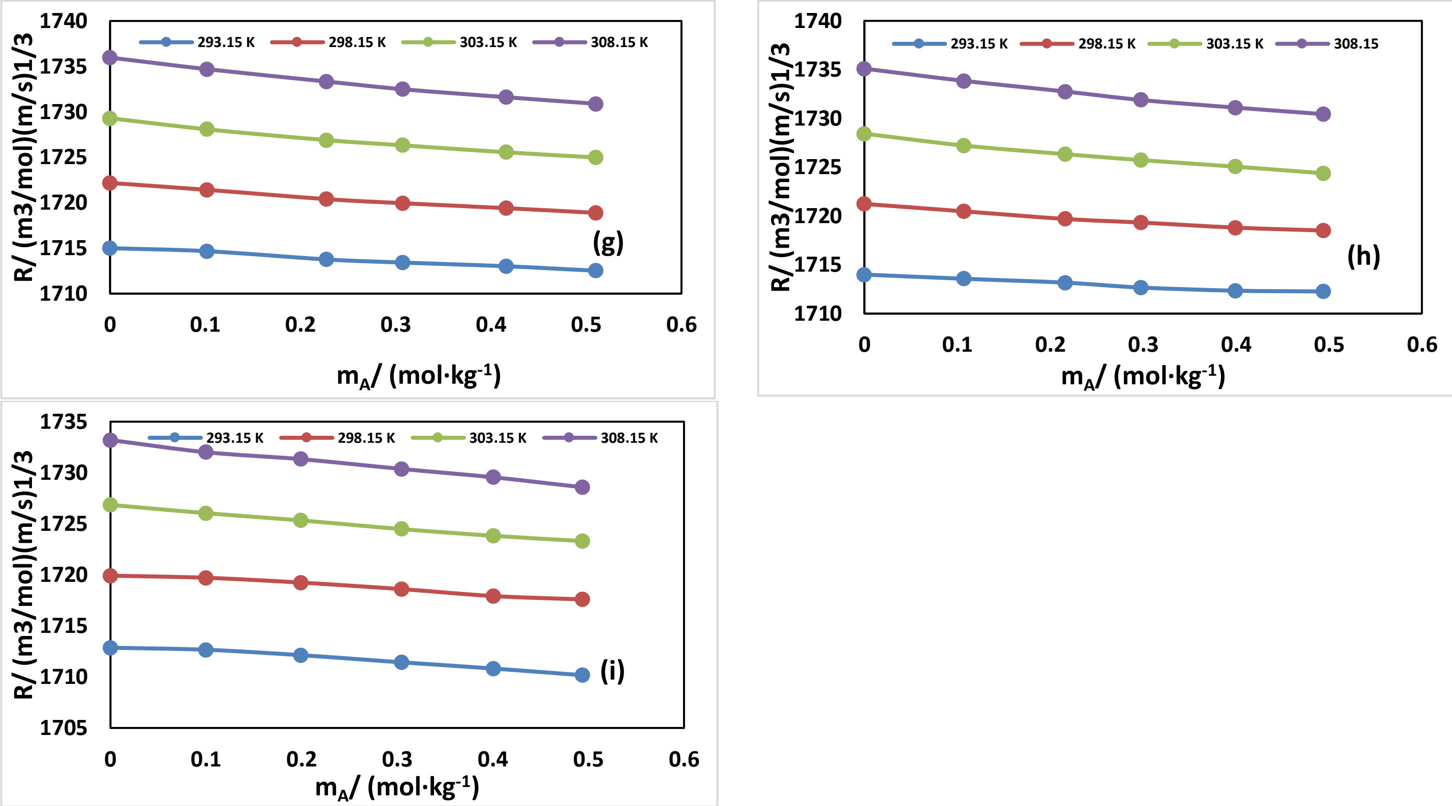


Figure 4. Variation of Rao's constant, R, of, EG **(a)** 0.02 Niacin, **(b)** 0.04 Niacin and **(c)** 0.06 Niacin; DEG **(d)** 0.02 Niacin, **(e)** 0.02 Niacin, **(f)** 0.04 Niacin; and TEG **(g)** 0.02 Niacin, **(h)** 0.02 Niacin, **(i)** 0.04 Niacin in different concentration of aqueous niacin solutions at different temperatures.

Table 3 Values of Wada's Constant (W) and Rao's Constant of glycols in an aqueous solution of D-Panthenol at different temperatures.

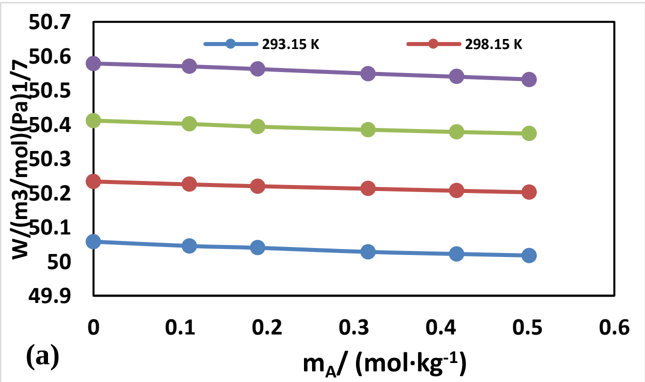
Molality (mol kg^{-1})	**Wada's Constant (W)(m^3 mol^{-1} Pa$^{1/7}$)**				**Rao's Constant (R)(m^{3}mol^{-1}Pa$^{1/3}$)**			
	293.15K	298.15K	303.15K	308.15K	293.15K	298.15K	303.15K	308.15K
0.02 mol kg^{-1} Niacin + EG								
0.0000	50.0579	50.2337	50.4117	50.5784	708.46	711.78	714.73	717.48
0.1107	50.0452	50.2251	50.4016	50.5698	708.34	711.64	714.56	717.34
0.1893	50.0398	50.2199	50.3937	50.5621	708.20	711.55	714.43	717.21
0.3166	50.0279	50.2125	50.3848	50.5489	708.16	711.43	714.28	717.00
0.4187	50.0219	50.2065	50.3783	50.5397	708.05	711.33	714.17	716.84
0.5025	50.0175	50.2020	50.3735	50.5318	707.86	711.26	714.09	716.71
0.04 mol kg^{-1} Niacin + EG								
0.0000	50.0291	50.2102	50.3902	50.5567	708.40	711.39	714.37	717.13
0.1022	50.0187	50.2041	50.3816	50.5497	708.23	711.29	714.23	717.01
0.1926	50.0106	50.1979	50.3746	50.5404	708.10	711.19	714.11	716.86
0.2853	50.0034	50.1940	50.3670	50.5306	707.98	711.13	713.99	716.69
0.3957	49.9958	50.1888	50.3594	50.5207	707.85	711.04	713.86	716.53
0.5359	49.9882	50.1819	50.3501	50.5113	707.73	710.93	713.71	716.37
0.06 mol kg^{-1} Niacin + EG								
0.0000	50.0032	50.1920	50.3698	50.5409	707.97	711.09	714.03	716.86
0.1148	49.9913	50.1853	50.3612	50.5332	707.78	710.98	713.89	716.74
0.1748	49.9876	50.1832	50.3574	50.5269	707.72	710.95	713.83	716.63
0.3093	49.9776	50.1778	50.3473	50.5143	707.55	710.86	713.66	716.42
0.4115	49.9729	50.1731	50.3421	50.5061	707.47	710.78	713.58	716.29
0.4915	49.9697	50.1690	50.3377	50.5018	707.42	710.71	713.50	716.22
0.02 mol kg^{-1} Niacin +DEG								
0.0000	85.5769	85.8837	86.1879	86.4730	1211.87	1216.92	1221.95	1226.67
0.0979	85.5819	85.8661	86.1603	86.4510	1211.94	1216.63	1221.50	1226.31
0.1896	85.5716	85.8538	86.1429	86.4240	1211.77	1216.43	1221.21	1225.86
0.2993	85.5594	85.8378	86.1203	86.3980	1211.56	1216.16	1220.83	1225.43
0.3731	85.5541	85.8268	86.1030	86.3826	1211.48	1215.98	1220.55	1225.17
0.5358	85.5350	85.8117	86.0809	86.3496	1211.16	1215.73	1220.18	1224.63
0.04 mol kg^{-1} Niacin +DEG								

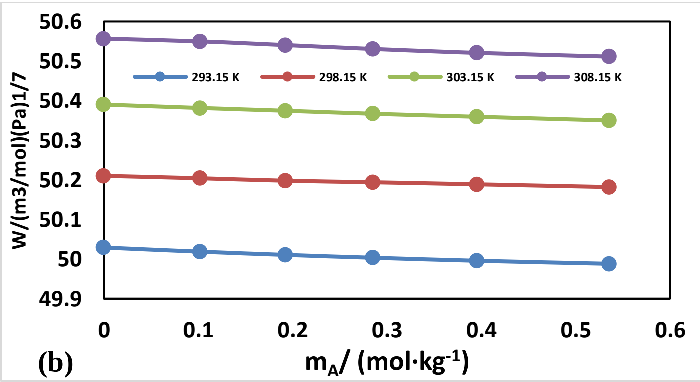
Molality (mol kg^{-1})	Wada's Constant (W)(m^3 mol^{-1} Pa$^{1/7}$)				Rao's Constant (R)(m^{3}mol^{-1}Pa$^{1/3}$)			
0.0000	85.5339	85.8435	86.1512	86.4360	1211.19	1216.26	1221.35	1226.06
0.1064	85.5423	85.8267	86.1266	86.4177	1211.28	1215.98	1220.94	1225.76
0.1906	85.5349	85.8192	86.1117	86.3971	1211.16	1215.86	1220.69	1225.41
0.2888	85.5286	85.8037	86.0959	86.3742	1211.05	1215.60	1220.43	1225.03
0.3994	85.5187	85.7927	86.0767	86.3541	1210.89	1215.42	1220.11	1224.70
0.4957	85.5060	85.7887	86.0670	86.3381	1210.68	1215.35	1219.95	1224.44
0.06 mol kg^{-1} Niacin +DEG								
0.0000	85.5195	85.8124	86.1164	86.4089	1210.59	1215.74	1220.77	1225.61
0.1098	85.5028	85.7941	86.0936	86.3915	1210.63	1215.44	1220.39	1225.32
0.2041	85.4988	85.7890	86.0802	86.3708	1210.56	1215.36	1220.17	1224.98
0.2594	85.4917	85.7814	86.0720	86.3565	1210.45	1215.23	1220.04	1224.74
0.3688	85.4884	85.7713	86.0593	86.3365	1210.39	1215.06	1219.83	1224.41
0.4976	85.4733	85.7638	86.0401	86.3164	1210.14	1214.94	1219.51	1224.08
0.02 mol kg^{-1} Niacin +TEG								
0.0000	121.1177	121.5418	121.9724	122.3758	1715.00	1722.18	1729.30	1735.97
0.1018	121.0874	121.4958	121.8988	122.2992	1714.67	1721.42	1728.08	1734.70
0.2273	121.0322	121.4341	121.8266	122.2168	1713.76	1720.40	1726.89	1733.34
0.3071	121.0116	121.4072	121.7924	122.1655	1713.42	1719.95	1726.32	1732.49
0.4162	120.9872	121.3736	121.7456	122.1124	1713.01	1719.40	1725.55	1731.61
0.5103	120.9572	121.3431	121.7112	122.0687	1712.52	1718.89	1724.98	1730.89
0.04 mol kg^{-1} Niacin +TEG								
0.0000	121.0568	121.48494	121.9203	122.3234	1714.00	1721.24	1728.44	1735.10
0.1072	121.0208	121.43885	121.8466	122.2476	1713.57	1720.48	1727.22	1733.85
0.2161	121.0015	121.39163	121.7938	122.1814	1713.17	1719.70	1726.34	1732.76
0.2976	120.9804	121.36946	121.7566	122.1292	1712.67	1719.33	1725.73	1731.89
0.3993	120.9650	121.33782	121.7163	122.0817	1712.35	1718.81	1725.06	1731.11
0.4943	120.9420	121.31981	121.6751	122.0415	1712.27	1718.51	1724.38	1730.44
0.06 mol kg^{-1} Niacin +TEG								
0.0000	120.9776	121.4053	121.8244	122.1982	1712.86	1719.92	1726.85	1733.20
0.0997	120.9559	121.3923	121.7755	122.1364	1712.66	1719.71	1726.04	1732.01
0.1990	120.9240	121.3642	121.7325	122.0955	1712.13	1719.24	1725.33	1731.33
0.3044	120.8917	121.3252	121.6813	122.0371	1711.43	1718.60	1724.48	1730.37
0.4006	120.8546	121.2842	121.6410	121.9874	1710.82	1717.92	1723.82	1729.55
0.4937	120.8152	121.2642	121.6102	121.9287	1710.17	1717.59	1723.31	1728.58

3.5. Wada's constant(W).

$$w = \frac{m_{eff}}{\rho}\beta^{\frac{1}{7}} \qquad \textit{Equation 5}$$

The Wada's constants are indexed in **Table 3** and are graphically represented in **Figure 5**.





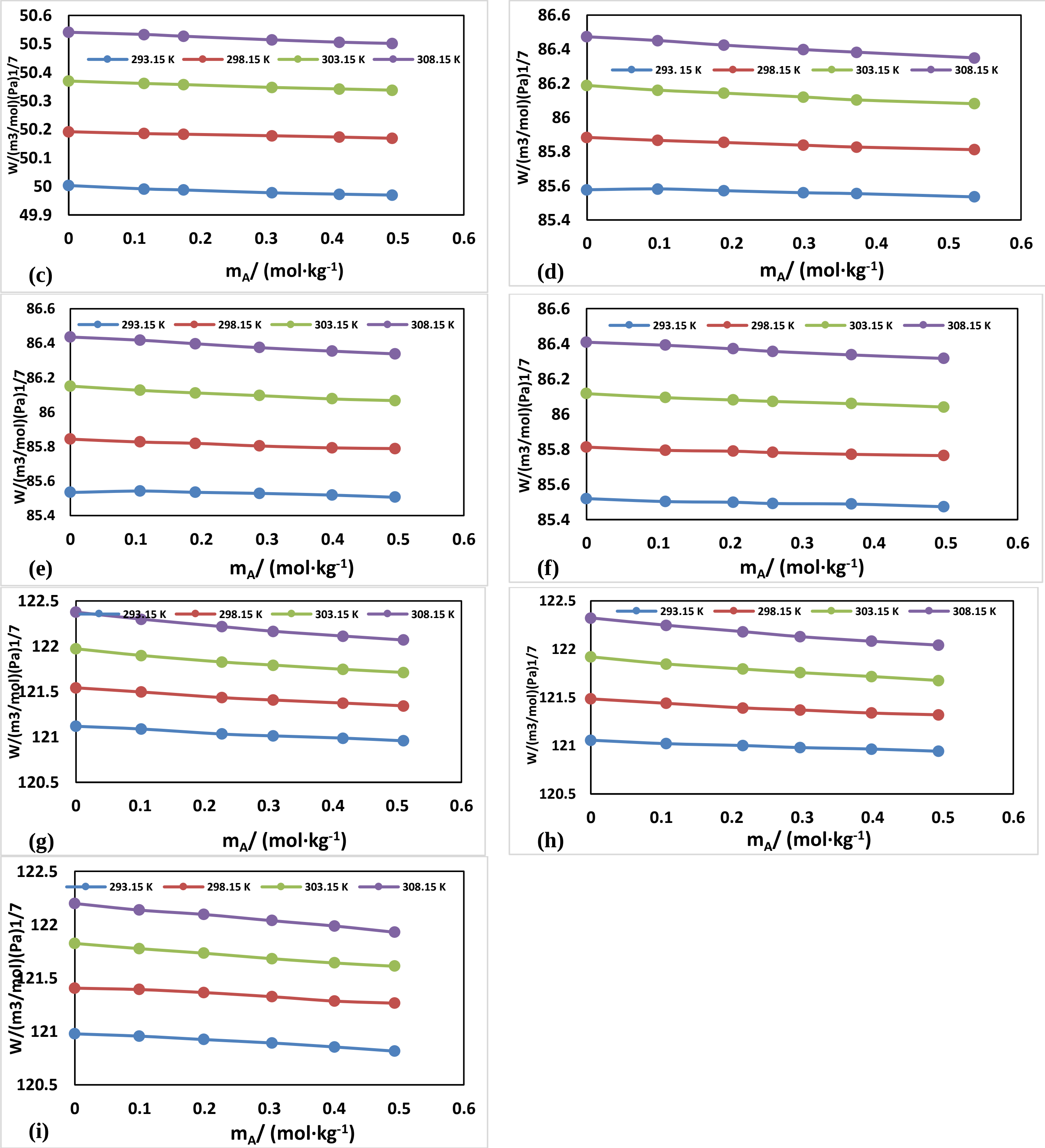
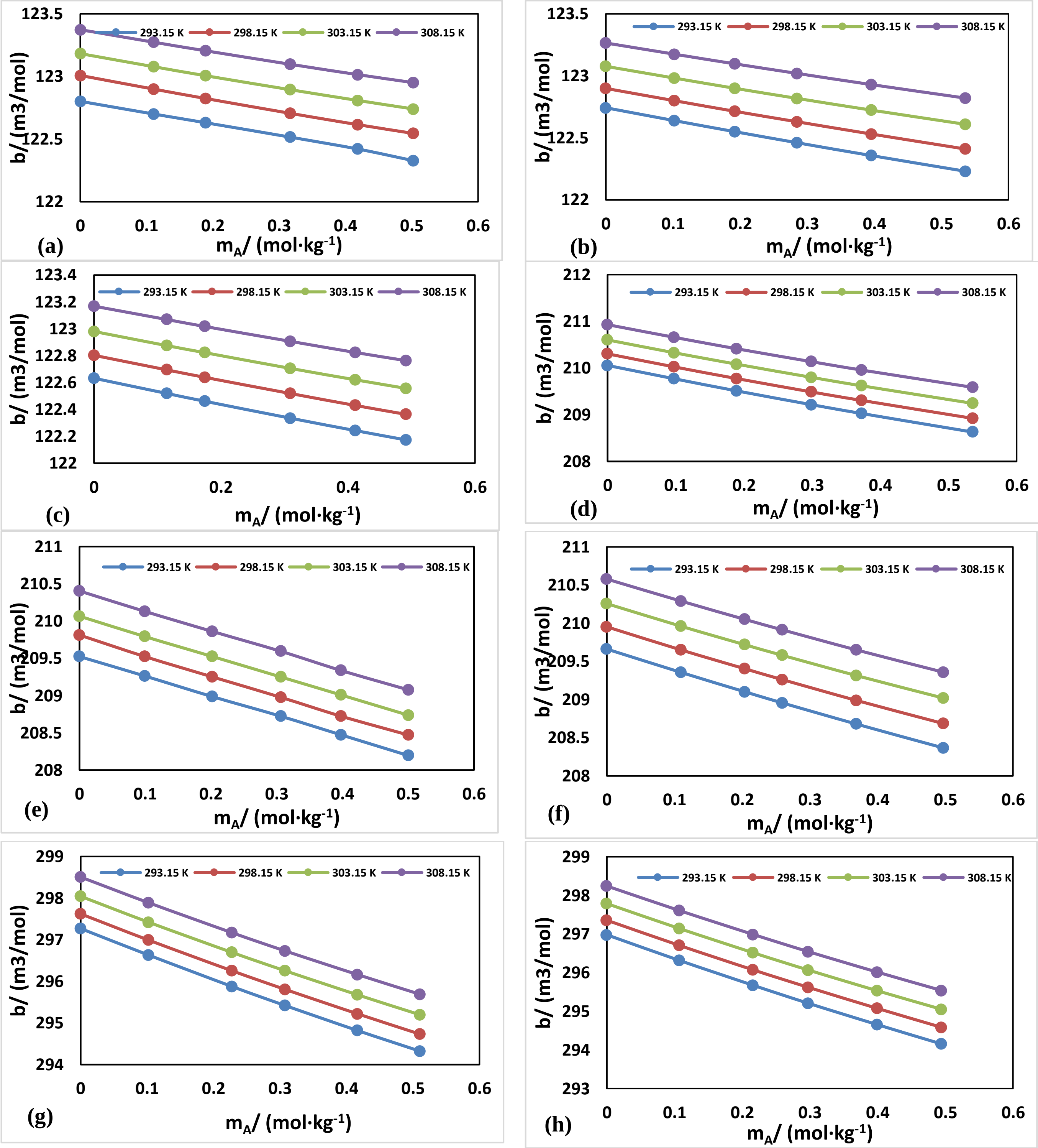


Figure 5. Variation of Wada's constant, W, of, EG **(a)** 0.02 Niacin, **(b)** 0.04 Niacin and **(c)** 0.06 Niacin; DEG **(d)** 0.02 Niacin, **(e)** 0.02 Niacin, **(f)** 0.04 Niacin; and TEG **(g)** 0.02 Niacin, **(h)** 0.02 Niacin, **(i)** 0.04 Niacin in different concentration of aqueous niacin solutions at different temperatures.

3.6. Vander Waal's Constant(b).

$$b = V_m[1 - (RT - MU^2)\{(1 + (\frac{MU^2}{3RT})) - 1\}] \qquad \textit{Equation 6}$$

The Vander Waal's values are indexed in **Table 4** and are graphically represented in **Figure 6**.



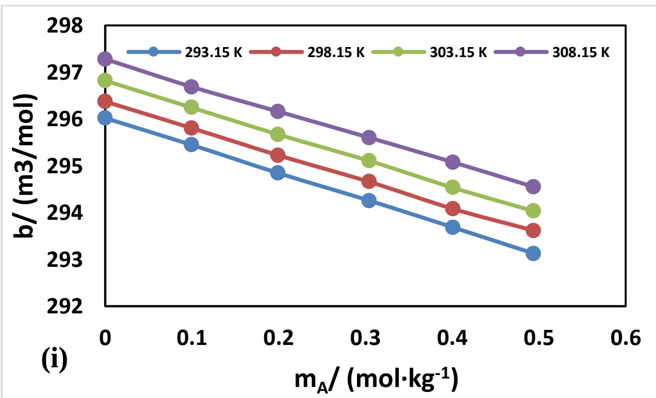


Figure 6. Variation of Vander Waal's constant, b, of, EG **(a)** 0.02 Niacin, **(b)** 0.04 Niacin and **(c)** 0.06 Niacin; DEG **(d)** 0.02 Niacin, **(e)** 0.02 Niacin, **(f)** 0.04 Niacin; and TEG **(g)** 0.02 Niacin, **(h)** 0.02 Niacin, **(i)** 0.04 Niacin in different concentration of aqueous niacin solutions at different temperatures.

Table 4. Values of Vander Waal's Constant (b) of glycols in an aqueous solution of niacin at different temperatures.

Molality (mol kg^{-1})	**Vander Waal's Constant (b)(m^3/mol)**			
	293.15K	298.15K	303.15K	308.15K
0.02 mol kg^{-1} Niacin + EG				
0.0000	122.8014	123.0078	123.1823	123.3732
0.1107	122.6999	122.8989	123.0777	123.2732
0.1893	122.6304	122.8237	123.0056	123.2045
0.3166	122.5157	122.7057	122.8943	123.0972
0.4187	122.4207	122.6152	122.8082	123.0143
0.5025	122.3279	122.5451	122.7403	122.9506
0.04 mol kg^{-1} Niacin + EG				
0.0000	122.7428	122.8989	123.0768	123.2650
0.1022	122.6390	122.7998	122.9820	123.1748
0.1926	122.5496	122.7139	122.8994	123.0966
0.2853	122.4605	122.6296	122.8180	123.0195
0.3957	122.3573	122.5310	122.7237	122.9295
0.5359	122.2307	122.4101	122.6093	122.8206
0.06 mol kg^{-1} Niacin + EG				
0.0000	122.6318	122.8024	122.9799	123.1682
0.1148	122.5185	122.6940	122.8745	123.0686
0.1748	122.4603	122.6382	122.8220	123.0168
0.3093	122.3346	122.5183	122.7050	122.9064
0.4115	122.2424	122.4294	122.6205	122.8237
0.4915	122.1728	122.3631	122.5563	122.7629
0.02 mol kg^{-1} Niacin + DEG				
0.0000	210.0557	210.3043	210.6026	210.9291
0.0979	209.7702	210.0245	210.3273	210.6574
0.1896	209.5104	209.7741	210.0818	210.4125
0.2993	209.2149	209.4876	209.8001	210.1357
0.3731	209.0252	209.3051	209.6186	209.9558
0.5358	208.6282	208.9214	209.2433	209.5866
0.04 mol kg^{-1} Niacin + DEG				
0.0000	209.5237	209.8129	210.0664	210.4046
0.0995	209.2625	209.5234	209.7923	210.1301
0.2020	208.9863	209.2512	209.5249	209.8614
0.3063	208.7225	208.9768	209.2498	209.5945
0.3979	208.4726	208.7230	209.0084	209.3370
0.5004	208.1945	208.4701	208.7363	209.0765
0.06 mol kg^{-1} Niacin + DEG				
0.0000	209.6614	209.9531	210.2565	210.5785
0.1098	209.3554	209.6498	209.9601	210.2897
0.2041	209.1012	209.4029	209.7179	210.0502
0.2594	208.9559	209.2611	209.5797	209.9131
0.3688	208.6786	208.9885	209.3141	209.6502
0.4976	208.3651	208.6847	209.0186	209.3577
0.02 mol kg^{-1} Niacin + TEG				
0.0000	297.2687	297.6207	298.0428	298.5048
0.1018	296.6334	296.9932	297.4229	297.8914
0.2273	295.8782	296.2557	296.6968	297.1709
0.3071	295.4216	295.8089	296.2566	296.7337
0.4162	294.8190	295.2210	295.6773	296.1635
0.5103	294.3225	294.7317	295.1976	295.6900
0.04 mol kg^{-1} Niacin + TEG				
0.0000	296.9796	297.3570	297.7875	298.2429
0.1072	296.3164	296.7049	297.1428	297.6076
0.2161	295.6737	296.0725	296.5167	296.9901
0.2976	295.2076	295.6210	296.0683	296.5448
0.3993	294.6561	295.0764	295.5329	296.0156
0.4943	294.1551	294.5858	295.0530	295.5401
0.06 mol kg^{-1} Niacin + TEG				
0.0000	296.0188	296.3733	296.8197	297.2808
0.0997	295.4460	295.8051	296.2438	296.6873
0.1990	294.8470	295.2273	295.6709	296.1622
0.3044	294.2562	294.6579	295.1054	295.6019
0.4006	293.6869	294.0821	294.5332	295.0787
0.4937	293.1277	293.6180	294.0332	294.5516

The linear variation in acoustic impedance shows the absence of specific interactions like complex formation in the binary mixture. The temperature variation is from 203.15 K to 308.15 K. The adiabatic compressibility decreases with increasing concentration due to the strong molecular interaction among the solute and solvent molecules shown. The variation in intermolecular free length [21-26]. This decrease in free length is due to the decreased adiabatic compressibility, which brings the molecules to be packed closely [27-32]. From the mathematical relations for acoustic impedance ($Z=\rho U$) and adiabatic compressibility ($\beta= 1/\rho U^2$), they must show opposite behavior, and adiabatic compressibility (β) and intermolecular free length ($Lf = KT \times \beta^{1/2}$) should exhibit the same behavior. This is reflected in the experimental results. [32-35].

The Wada constant changes with molality at different temperatures show that solute-solvent molecules are coming close to each other, and the space between them decreases with a temperature rise. This supports the strong solute-solvent interaction in liquid solution. Rao's constant or molar sound velocity shows an increasing trend with an 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 a greater number of components in a given region, thus leading to close packing of the medium, thereby increasing the interactions showing strong solute-solvent interaction existing in the solution [34-36].

4. Conclusions

The linear variation in acoustic impedance shows the absence of specific interactions like complex formation in the binary mixture. The adiabatic compressibility decreases with increasing concentration due to the strong molecular interaction among the solute and solvent molecules. Due to the decreased adiabatic compressibility, which brings the molecules to be packed closely, there is a decrease in free length. The decrease of Vander Waal's Constant with an increase in concentration implies weak interaction between the molecules of the mixture.

Funding

This paper received no external funding.

Acknowledgments

This paper and the research behind it would not have been possible without the exceptional support of my supervisor, Dr. Kailash Chandra Juglan. His enthusiasm, knowledge, and exacting attention to detail have inspired me and kept my work on track. Dr. Nabaparna Chakraborty and Manisha Lamba, my colleagues at Lovely Professional University, have also looked over my transcriptions and answered numerous questions about the subject with unfailing patience.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Chakraborty, N.; Juglan, K.C.; Kumar, H. Volumetric and ultrasonic study of polyethylene glycols in aqueous solutions of niacin at different temperatures. *The Journal of Chemical Thermodynamics* **2021**,

106326, 154, https://doi.org/10.1016/j.jct.2020.106326.

2. Chakraborty, N.; Juglan, K. C.; Kumar, H. Volumetric and ultrasonic studies of molecular interactions of glycols in aqueous niacin (vitamin B3) at different temperatures. *Journal of Molecular Liquids* **2021**, *115869*,332, https://doi:10.1016/j.molliq.2021.115869.
3. Banipal, P.K.; Arti, S.; Banipal, T.S. Influence of NH4Br on Solvation Behavior of Polyhydroxy Solutes in Aqueous Solutions at Different Temperatures and Atmospheric Pressure. *Journal of Chemical & Engineering Data* **2015**, *60*, 1023–1047, https://doi.org/10.1021/je500886a.
4. Chakraborty, N.; Juglan, K.C.; Kumar, H. Study of Thermodynamic and Acoustic Properties of Niacin in Aqueous Hexylene Glycol and Propylene Glycol at Different Temperatures. *ACS Omega* **2020**, *5*, 32357–32365, https://doi.org/10.1021/acsomega.0c04292.
5. Knopp, R.H. Evaluating niacin in its various forms. *The American Journal of Cardiology* **2000**, *86*, 51–56, https://doi.org/10.1016/s0002-9149(00)01471-5.
6. Yue, H.; Zhao, Y.; Ma, X.; Gong, J. Ethylene glycol: properties, synthesis, and applications. *Chemical Society Reviews* **2012**, *41*, 4218, https://doi.org/10.1039/c2cs15359a.
7. Periyasamy, K. Ultrasonic studies of molecular interaction of alcohols with non-polar solvents. *RASAYAN J. Chem* **2012,** 4, 4671-4676.
8. Kaur, K.; Juglan, K.C. Studies of molecular interaction in the binary mixture of chloroform and methanol by using ultrasonic technique. *Der Pharma Chemica* **2015,** *7*, 160-167.
9. Kaur, K.; Behal, I.; Juglan, K.C.; Kumar, H. Volumetric and ultrasonic studies on interactions of ethylene glycol, diethylene glycol and triethylene glycol in aqueous solutions of glycerol at temperatures T = (293.15 K − 308.15) K. *The Journal of Chemical Thermodynamics* **2018**, *125*, 93-106, 0021-9614, https://doi.org/10.1016/j.jct.2018.05.01.
10. Thakur A.; Juglan K.C.; Kumar H.; Kaur K. Investigation on molecular interaction of glycols in methanol solutions of methylparaben (methyl 4 – hydroxybenzoate) at different temperatures through thermo-acoustical analysis. *Journal of Molecular Liquids* **2019**, *228*, 111014, 0167-7322, https://doi.org/10.1016/j.molliq.2019.111014.
11. Kaur, K.; Juglan, K.C.; Kumar H. Acoustical and volumetric investigation of polyethylene glycol 400 and polyethylene glycol 4000 in aqueous solutions of glycerol at different temperatures. *The Journal of Chemical Thermodynamics* **2018**, *127*, 8-16, https://doi.org/10.1016/j.jct.2018.07.015.
12. Chakraborty, N.; Juglan, K.C.; Kumar, H. Volumetric and ultrasonic studies of molecular interactions of glycols in aqueous niacin (vitamin B3) at different temperatures. *Journal of Molecular Liquids* **2021**, *332*, 115869, https://doi.org/10.1016/j.molliq.2021.115869.
13. Gowrisankar, M.; Venkateswarlu, P.; Sivakumar, K.; Sivarambabu, S. Ultrasonic Studies on Molecular Interactions in Binary Mixtures of N-Methyl Aniline with Methyl Isobutylketone, +3-Pentanone, and +Cycloalkanones at 303.15 K. *Journal of Solution Chemistry* **2013**, *42*, 916–935, https://doi.org/10.1007/s10953-013-0003-0.
14. Nath, G.; Paikaray, R. Ultrasonic study of binary mixtures of acetone with chlorobenzene at different frequencies. *Indian Journal of Physics* **2009,** *83*, 1309–1314, https://doi.org/10.1007/s12648-009-0111-2.
15. Ali, A.; Hyder, S.; Nain, A.K. Studies on molecular interactions in binary liquid mixtures by viscosity and ultrasonic velocity measurements at 303.15 K. *Journal of Molecular Liquids* **1999,** *79*, 89–99, https://doi.org/10.1016/s0167-7322(98)00105-6.
16. Pandey, J.D.; Kumar, V.; Saxena, M.C. Evaluation of Jacobson's constant and intermolecular free-length as a function of pressure and temperature for cryogenic liquids. *Ultrasonics* **1979,** *17*, 153–158, https://doi.org/10.1016/0041-624x(79)90032-5.
17. Kanwar, A.; Mhatre, P. Determination of Wada Constant, Rao' Constant, Compressibility Andviscosity of A Cholesteric Liquid Crystal Solution at Various Temperatures. *IJERT*, **2014,** *03*.
18. Singh, J.; Sharma, R. Variation of Wada Constant, Raos Constant and Acoustic Impedance of Aqueous Cholesteryl Oleyl Carbonate with Temperature. *Indian Journal of Pharmaceutical Education and Research* **2013,** https://doi.org/10.5530/ijper.54.3.112.
19. Panda, S. Molecular Interaction of Polymer Dextran in Sodium Hydroxide through Evaluation of Thermo Acoustic Parameters. *Indian Journal of Pharmaceutical Education and Research* **2020,** *54*, 630-636.
20. Panda, S.; Mahapatra, A.P. Study of Acoustic and Thermodynamic Properties of Aqueous Solution of Dextran at Different Concentration and Temperature through Ultrasonic Technique. *International Journal of Science and Research* **2015,** 2319-7064.
21. Kaur, K.; Juglan, K. Studies of molecular interaction in the binary mixture of chloroform and methanol by using ultrasonic technique. *Der Pharma Chemica* **2015,** *7*, 160-167.
22. Ravi, S.; Amoros, J.; Arockia Jayalatha, K. Effective Method of Characterizing Specific Liquid Fluorocarbon Interactions Using Ultrasound. *The Journal of Physical Chemistry B* **2008**, *112*, 6420–6425, https://doi.org/10.1021/jp800812c.
23. Chakraborty, N.; Juglan, K.C.; Kumar, H. Thermodynamics of various interactions in homologous series of polyethylene glycols in aqueous medium of D-panthenol at T = (288.15, 298.15, 308.15 and 318.15) K: a volumetric and acoustic approach. *Braz. J. Chem. Eng.* **2021**, https://doi.org/10.1007/s43153-021-00163-w.
24. Kaur, K.; Juglan, K.C.; Kumar, H.; Investigation on Temperature-Dependent Volumetric and Acoustical

Properties of Homologous Series of glycols in aqueous sorbitol solutions, *Journal of Chemical & Engineering* **2021,** *62*, 3769-3782, https://doi.org/10.1021/acs.jced.7b00501.
25. Kaur, K.; Juglan, K.C.; Kumar H.; Temperature dependent physicochemical studies of polyethylene glycols (PEG-400 and PEG-4000) in aqueous sorbitol solutions. *Journal of Molecular Liquids* **2018**, *268*, 700-706, https://doi.org/10.1016/j.molliq.2018.07.101.
26. Kaur, K.; Juglan K.C.; Kumar H.; Behal I. *Journal of Chemical & Engineering* **2018,** *63*, 3237-3251 https://doi.org/10.1021/acs.jced.8b00058.
27. Kaur, P.; Chakraborty, N.; Juglan, K.C.; Kumar, H.; Singla M. Temperature dependent physicochemical studies propylene and hexylene glycols in methanol solutions of chlorhexidine. *Journal of Molecular Liquids* **2021**, *339*, 116810.
28. Kaur, H.; Chakraborty, N.; Juglan, K.C.; Kumar H. Volumetric and Acoustic Behavior of PEG-200 and PEG-600 in Aqueous D-Mannitol solutions at Different Temperatures. *Journal of Solution Chemistry* **2021,** *50*, 1079–1102.
29. Jain, A.; Kaur, P.; Juglan, K.C.; Rheological Study of Reduced Graphene Oxide–Ethylene Glycol Nanosuspension for Ink. *Russian Journal of Physical Chemistry* **2021**, *95*, 8, 1671–1676.
30. Chakraborty, N.; Juglan K.C.; Kumar, H.; Thermodynamics of various interactions in homologous series of polyethylene glycols in aqueous medium of d-panthenol at T = (288.15, 298.15, 308.15 and 318.15) K: a volumetric and acoustic Approach. *Brazilian Journal of Chemical Engineering* **2021,** https://doi.org/10.1007/s43153-021-00163-w.
31. Chakraborty, N.; Juglan K.C.; Kumar, H. *Temperature-dependent thermodynamic and physicochemical studies of glycols in aqueous biotin solutions. Journal of Molecular Liquids* **2021,** *332*, 116605.
32. Chakraborty, N.; Kumar, H.; Juglan, K.C. Volumetric and Ultrasonic Studies of Molecular Interactions of PEG 400 and PEG 4000 in aqueous niacin solutions at Different Temperatures. *Journal of Chemical Engineering and Data* **2021,** https://doi.org/10.1021/acs.jced.0c01091.
33. Chakraborty, N.; Juglan, K.C.; Kumar, H. Volumetric and ultrasonic study of polyethylene glycols in aqueous solutions of niacin at different temperatures. *Journal of Molecular Liquids* **2021**, *332*, 15, 115869.
34. Chakraborty, N.; Juglan, K.C.; Kumar, H. Volumetric and ultrasonic study of polyethylene glycols in aqueous solutions of niacin at different temperatures. *J. Chem. Thermodynamics* **2021,** *154*, 106326.
35. Chakraborty, N.; Juglan K.C.; Kumar, H.; Study of Thermodynamic and Acoustic Properties of Niacin in Aqueous Hexylene Glycol and Propylene Glycol at Different Temperatures. *ACS Omega* **2021**, *5*, 50, 32357–32365.
36. Chawla, D.; Chakraborty, N.; Juglan, K.C.; Kumar, H. Temperature-dependent physicochemical studies of some glycols in aqueous d-mannitol solution. *Chemical Papers* **2021**, *75*, 1497–1506, https://doi.org/10.1007/s11696-020-01403-y.