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Study of Molecular Interaction of PEG-200 and PEG-600 in Aqueous D-Mannitol Solutions at Different Temperatures

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Abstract: The density and speed of sound for polyethylene glycols (PEG-200 and PEG-600) in an aqueous solution of D-Mannitol have been measured by Anton Paar DSA 5000M at different temperatures and concentrations. Experimentally obtained data of density and speed of sound are employed to calculate various theoretical parameters such as intermolecular free length, acoustic impedance, adiabatic compressibility, Wada's constant, Rao's Constant, and Vander Waal's constant, which gave the better insight into molecular interactions between the polyethylene glycols and D-mannitol solutions.

Keywords: density; the speed of sound; polyethylene glycols.

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1. Introduction

In the medical field, the use of chemicals attains attention in every sector, including ultrasonic behavior. When combined with other water resources, ultrasonic techniques are important to investigate molecular interactions. Ultrasonic techniques are widely used to learn about the different types of interaction present in the mixtures' molecules [1-4]. In the present years, ultrasonic techniques play a crucial role in finding physicochemical behavior. Ultrasonic techniques are an effective source of information about the structural and molecular changes in the mixture of liquid [5,6]. It is an interesting technique to study the properties of liquid-liquid mixtures, electrolytic solutions, and polymeric solutions. These mixtures have many applications in the pharmaceutical, leather, textiles, food, and chemical industries [7-9].

Volumetric and acoustical properties play an important role in examining structural properties. Polyethylene glycols are polyether compounds with numerous applications from modern manufacturing to medication. Polyethylene glycols belong to the polymer family, H-(O-CH_2+CH_2)-H-OH. The liquid form of the polymer plays a very important role in everyday life due to its extraordinary properties. Polyethylene is formed by various methods in addition to the polymerization of ethane. Polyethylene is commonly used in plastic, and its essential use is to make plastic bags, plastic films, containers including bottles, etc. [10].

D-Mannitol is a sugar alcohol and also has an acoustic property. D-Mannitol is a kind of sugar alcohol (polyol) used in medication due to its beneficial activity on the brain, kidneys, and heart. D-Mannitol is found in nature, especially in exudates from trees, and in marine green

growth and crisp mushrooms. D-Mannitol is economically accessible in an assortment of powder and granular structures [11,12]. In the present work, the physicochemical behavior of polyethylene glycols in an aqueous D-Mannitol solution has been investigated by using the density and speed of sound data at different temperatures. The density and velocity data were utilized to calculate the ultrasonic parameters such as adiabatic compressibility, acoustic impedance, intermolecular free length, Wada's constant, Rao's constant, and Vander Waal's constant.

2. Materials and Methods

For the present investigation, polyethylene glycols with molar mass 200 g·mol^{-1}, and 600 g·mol^{-1}, respectively, and D-Mannitol with molar mass 182.17 g·mol^{-1} are utilized. Chemicals have a purity of the order of ≥0.99. These chemicals were purchased from Loba Chemie Pvt. Ltd., India. All the solutions used in the measurement have been prepared in distilled water, and weighing was done by Sartorius CPA 225D balance with accuracy (±0.00001g). The Anton Paar density sound analyzer (DSA) 5000M is used to measure the density and speed of sound at different temperatures (293.15, 298.15, 303.15, and 308.15) K and constant frequency, i.e., 3 MHz. It is a two-in-one device that measures the density and speed of sound simultaneously and works on the piezoelectric effect. Fresh samples were made on the same day of measurements to prevent any aging effects. The syringe was used for inserting the samples into the device DSA (Density sound analyzer) very carefully (avoid air bubbles). After insert, the sample set the required temperature value, and the value of density and speed of sound was noticed from DSA. After obtaining, the syringe is taken out then the syringe and tube are washed with ether. The same further procedure has been used for other samples.

2.1. Theoretical considerations

The following equations are used to evaluate theoretical parameter intermolecular free length, acoustic impedance, adiabatic compressibility, Wada's constant, Rao's Constant, and Vander Waal's constant.

Acoustic impedance $$Z = \rho \times c \quad (1)$$

Adiabatic compressibility $$\beta = {}^{1}/_{[\rho(c^2)]} \quad (2)$$

Wada's constant $$W = (\beta)^{-\frac{1}{7}}\left(\frac{M}{\rho}\right) \quad (3)$$

Rao's Constant $$R = {}^{[(c^{\frac{1}{3}})M]}/_{\rho} \quad (4)$$

Intermolecular free length $$L_f = K_T (\beta)^{1/2} \quad (5)$$

Vander Waal's constant $$b = \left(\frac{M}{\rho}\right)[1 - (RT/Mc^2)\sqrt{1 + (Mc^2/3RT)} - 1] \quad (6)$$

3. Results and Discussion

The density and ultrasonic speed for PEG-200 and PEG-600 in (0.01, 0.03, and 0.05) mol.kg^{-1} D-Mannitol at different temperatures is obtained experimentally [13-15].

Experimental data utilized for calculated ultrasonic parameters are reported in Tables 1-6. Table 1 indicates the acoustic impedance values, and acoustic impedance values increase with the increase in molality and temperatures. The acoustic impedance value varies linearly with molality, which indicates the presence of strong interaction between the liquid mixtures and the acoustic impedance graphically represented in Figure 1**.** In Table 2, the decrease in the adiabatic compressibility with an increase in molality indicates the bond strength among molecules [16], and variation is shown in Figure 2**.** The variation of the Wada constant depicts the space between the solute and solvent molecules [17-19]. Table 3 and Figure 3. Represent the values and variation of Wada constant with molality and concentration. The Wada's constant decrease with an increase in molality and increase in temperatures [20]. The values of Rao's constant, intermolecular free length and Vander Waal constant also increase with the increase in temperature and decrease with increase in molality. Values are given in Table 4, 5, 6 and graphically represented in Figures 4, 5, and 6, respectively. Intermolecular free length depicts the strong solute-solvent interactions. The strong binding force is confirmed by the variation of the Vander Waal constant [21,22].

Table 1. Values of Acoustic impedance of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

$^{a}m_A$ / (mol.kg^{-1})	Z/ (kg m^{-2}S $^{-1}$)			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
PEG 200 + 0.01 m D-Mannitol				
0.00000	1480.618	1493.437	1504.088	1512.642
0.10160	1494.933	1507.628	1518.250	1525.673
0.20371	1509.396	1522.502	1532.734	1538.699
0.30012	1522.468	1536.284	1546.039	1551.231
0.40211	1537.168	1551.070	1560.619	1564.555
0.49810	1550.394	1564.726	1573.914	1576.946
PEG 200 + 0.03 m D-Mannitol				
0.00000	1484.871	1497.442	1507.683	1516.365
0.10516	1498.830	1512.234	1522.308	1529.952
0.20753	1513.161	1527.091	1536.545	1543.323
0.30249	1526.425	1540.757	1549.572	1555.394
0.41702	1542.728	1557.410	1565.588	1570.449
0.49987	1554.180	1569.797	1577.411	1581.125
PEG 200 + 0.05 m D-Mannitol				
0.00000	1489.131	1501.452	1511.283	1520.093
0.11021	1504.190	1517.130	1525.941	1534.542
0.20923	1518.035	1531.429	1539.012	1547.518
0.30703	1531.417	1545.879	1551.840	1560.508
0.39832	1544.394	1559.327	1564.075	1572.636
0.50431	1559.304	1575.217	1577.634	1586.716
PEG 600 + 0.01 m D-Mannitol				
0.00000	1483.188	1496.909	1507.067	1516.588
0.10007	1526.090	1536.92	1547.997	1555.153
0.19940	1567.976	1579.567	1588.054	1593.849
0.30387	1612.554	1623.605	1630.708	1635.345
0.40836	1658.095	1667.935	1673.539	1677.163
0.51045	1702.070	1712.505	1716.259	1718.419
PEG 600 + 0.03 m D-Mannitol				
0.00000	1487.812	1502.009	1510.652	1520.922
0.10164	1531.645	1543.818	1551.132	1559.823
0.19998	1573.766	1584.491	1590.872	1598.548
0.29836	1616.368	1626.210	1631.909	1638.256
0.40338	1662.135	1671.077	1675.085	1680.580
0.50796	1707.447	1716.593	1719.346	1723.080

$^{a}m_A$ / (mol.kg^{-1})	Z/ (kg m^{-2}S $^{-1}$)			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
PEG 600 + 0.05 m D-Mannitol				
0.00000	1496.011	1508.060	1514.624	1524.413
0.10321	1540.350	1550.584	1556.248	1564.556
0.20127	1581.846	1591.407	1596.178	1603.461
0.29925	1624.357	1633.087	1637.158	1643.354
0.40027	1669.417	1676.852	1679.071	1684.514
0.50798	1717.265	1723.932	1725.504	1728.478

$^{a}m_A$ is the molality of polyethylene glycols in the aqueous solution D-Mannitol

Table 2. Values of adiabatic compressibility of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

$^{a}m_A$ / (mol.kg^{-1})	β ×10^{-10}/ (N/m^2)			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
PEG 200 + 0.01 m D-Mannitol				
0.00000	4.556666	4.473451	4.404348	4.347548
0.10160	4.482550	4.402119	4.334898	4.285770
0.20371	4.409604	4.328860	4.265525	4.225642
0.30012	4.345857	4.262998	4.203724	4.168846
0.40211	4.275216	4.193959	4.137266	4.109794
0.49810	4.213768	4.132090	4.078513	4.056245
PEG 200 + 0.03 m D-Mannitol				
0.00000	4.537094	4.455699	4.389762	4.332452
0.10516	4.465808	4.381498	4.318086	4.267924
0.20753	4.393866	4.308667	4.250192	4.205927
0.30249	4.329005	4.243505	4.189837	4.151540
0.41702	4.251176	4.166154	4.117248	4.084993
0.49987	4.198155	4.109865	4.064878	4.038989
PEG 200+ 0.05 m D-Mannitol				
0.00000	4.517634	4.438041	4.375242	4.317426
0.11021	4.440975	4.359848	4.304408	4.249164
0.20923	4.372114	4.290393	4.242992	4.189441
0.30703	4.307465	4.221772	4.184229	4.130919
0.39832	4.245867	4.159547	4.129216	4.077534
0.50431	4.177002	4.087733	4.070202	4.016982
PEG 600 + 0.01 m D-Mannitol				
0.00000	4.544173	4.457903	4.390034	4.330301
0.10007	4.330411	4.260927	4.198434	4.151379
0.19940	4.137516	4.071940	4.022059	3.984025
0.30387	3.946782	3.887974	3.847455	3.816433
0.40836	3.766819	3.716003	3.684015	3.659360
0.51045	3.605412	3.555492	3.531416	3.514092
PEG 600 + 0.03 m D-Mannitol				
0.00000	4.522521	4.432590	4.375391	4.311759
0.10164	4.305175	4.231940	4.185215	4.133532
0.19998	4.112582	4.051000	4.011320	3.967349
0.29836	3.931640	3.877806	3.843708	3.807892
0.40338	3.752134	3.704609	3.679979	3.650127
0.50796	3.587321	3.541590	3.522471	3.501500
PEG 600 + 0.05 m D-Mannitol				
0.00000	4.490512	4.408464	4.359018	4.298927
0.10321	4.272450	4.206189	4.164481	4.115218
0.20127	4.085018	4.026341	3.991643	3.949732
0.29925	3.906072	3.855348	3.825673	3.791066
0.40027	3.729812	3.687968	3.668281	3.638276
0.50798	3.556986	3.520928	3.504637	3.486736

Table 3. Values of Wada constant *W*, of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

$^{a}m_A$ / (mol.kg^{-1})	W/ (m^3 /mol) (Pa)$^{1/7}$			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
PEG 200+ 0.01 m D-Mannitol				
0.00000	161.2145	161.8319	162.4123	162.9805
0.10160	161.1338	161.7440	162.3183	162.8503
0.20371	161.0523	161.6703	162.2288	162.7108
0.30012	160.9551	161.5893	162.1304	162.5877
0.40211	160.8763	161.5090	162.0395	162.4574
0.49810	160.7816	161.4208	161.9391	162.3294
PEG 200 + 0.03 m D-Mannitol				
0.00000	161.0828	161.7007	162.2525	162.8271
0.10516	160.9839	161.6251	162.1728	162.7148
0.20753	160.9080	161.5611	162.0907	162.6041
0.30249	160.8343	161.4960	162.0034	162.4892
0.41702	160.7515	161.4193	161.9074	162.3596
0.49987	160.6795	161.3711	161.8401	162.2612
PEG 200 + 0.05 m D-Mannitol				
0.00000	160.9513	161.5697	162.0931	162.6741
0.11021	160.8604	161.4953	161.9876	162.5591
0.20923	160.7858	161.4293	161.8849	162.4513
0.30703	160.7009	161.3718	161.7776	162.3472
0.39832	160.6342	161.3149	161.6836	162.2469
0.50431	160.5495	161.2545	161.5525	162.1288
PEG 600 + 0.01 m D-Mannitol				
0.00000	483.4839	485.1736	487.1212	488.6151
0.10007	482.5350	484.6360	485.8603	487.6403
0.19940	481.5343	483.2360	484.8670	486.6031
0.30387	480.5094	482.1931	483.7588	485.4907
0.40836	479.3750	481.1466	482.6754	484.2943
0.51045	478.2738	480.0514	481.6794	483.1773
PEG 600 + 0.03 m D-Mannitol				
0.00000	483.1132	485.0304	486.6671	488.2225
0.10164	482.2519	484.0767	485.6453	487.1172
0.19998	481.3111	483.0752	484.6289	486.0706
0.29836	480.3502	482.0904	483.5856	485.0069
0.40338	479.1822	481.0245	482.3887	483.7214
0.50796	478.0062	479.9114	481.3445	482.5426
PEG 600 + 0.05 m D-Mannitol				
0.00000	481.7265	484.1563	486.1964	487.6477
0.10321	480.9929	483.2198	485.2036	486.6380
0.20127	480.0821	482.2393	484.1254	485.5597
0.29925	479.1966	481.2222	483.0790	484.4483
0.40027	478.2612	480.1810	481.8512	483.2571
0.50798	477.1648	479.0271	480.6956	481.8546

Table 4. Values of Rao constant, of polyethylene glycols 200,600 in aqueous D-Mannitol solution at different temperatures.

$^{a}m_A$ / (mol.kg^{-1})	R/ (m^3 /mol) (m/s)$^{1/3}$			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
PEG 200 + 0.01 m D-Mannitol				
0.00000	2282.793	2292.996	2302.592	2311.993
0.10160	2281.459	2291.543	2301.038	2309.838
0.20371	2280.113	2290.324	2299.558	2307.531
0.30012	2278.509	2288.986	2297.931	2305.494
0.40211	2277.207	2287.659	2296.428	2303.338
0.49810	2275.643	2286.202	2294.768	2301.222
PEG 200 + 0.03 m D-Mannitol				

$^{a}m_A$ / (mol.kg^{-1})	R/ (m^3 /mol) (m/s)$^{1/3}$			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
0.00000	2280.617	2290.827	2299.949	2309.455
0.10516	2278.984	2289.577	2298.631	2307.597
0.20753	2277.730	2288.52	2297.274	2305.765
0.30249	2276.512	2287.443	2295.831	2303.865
0.41702	2275.146	2286.175	2294.244	2301.720
0.49987	2273.956	2285.379	2293.130	2300.094
PEG 200 + 0.05 m D-Mannitol				
0.00000	2278.446	2288.662	2297.314	2306.923
0.11021	2276.945	2287.433	2295.570	2305.022
0.20923	2275.712	2286.342	2293.872	2303.238
0.30703	2274.311	2285.391	2292.098	2301.516
0.39832	2273.209	2284.451	2290.544	2299.857
0.50431	2271.810	2283.454	2288.377	2297.904
PEG 600 + 0.01 m D-Mannitol				
0.00000	6845.741	6873.662	6905.864	6930.578
0.10007	6830.069	6864.776	6885.014	6914.450
0.19940	6813.547	6841.647	6868.594	6897.294
0.30387	6796.630	6824.424	6850.283	6878.903
0.40836	6777.915	6807.146	6832.388	6859.130
0.51045	6759.752	6789.073	6815.942	6840.677
PEG 600+ 0.03 m D-Mannitol				
0.00000	6839.617	6871.295	6898.353	6924.083
0.10164	6825.394	6855.534	6881.459	6905.797
0.19998	6809.862	6838.991	6864.659	6888.490
0.29836	6794.004	6822.727	6847.420	6870.907
0.40338	6774.734	6805.132	6827.653	6849.665
0.50796	6755.340	6786.764	6810.413	6830.194
PEG 600+ 0.05 m D-Mannitol				
0.00000	6816.719	6856.849	6890.570	6914.573
0.10321	6804.610	6841.378	6874.158	6897.873
0.20127	6789.580	6825.186	6856.340	6880.044
0.29925	6774.971	6808.394	6839.054	6861.674
0.40027	6759.545	6791.212	6818.779	6841.995
0.50798	6741.469	6772.175	6799.703	6818.834

Table 5. Values of the intermolecular free length of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

$^{a}m_A$ / (mol.kg^{-1})	L_f /(Å)			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
PEG 200 + 0.01 m D-Mannitol				
0.00000	4.341319	4.3490787	4.3547067	4.365631
0.10160	4.305802	4.3142647	4.3202366	4.334503
0.20371	4.271558	4.2782159	4.2855279	4.303989
0.30012	4.240130	4.2455453	4.2543694	4.274967
0.40211	4.201056	4.2110266	4.220606	4.244581
0.49810	4.173471	4.1798508	4.1905305	4.216838
PEG 200+ 0.03 m D-Mannitol				
0.00000	4.329968	4.3404409	4.3474901	4.358045
0.10516	4.296738	4.3041482	4.3118511	4.325469
0.20753	4.260316	4.2682260	4.2778189	4.293937
0.30249	4.231176	4.2358277	4.2473365	4.266084
0.41702	4.190095	4.1970445	4.2103832	4.231755
0.49987	4.163715	4.1685947	4.1835203	4.207859
PEG 200 + 0.05 m D-Mannitol				
0.00000	4.321650	4.3318317	4.3402939	4.350481
0.11021	4.283750	4.2935014	4.3050165	4.315952
0.20923	4.253331	4.2591647	4.274194	4.285514

$^{a}m_A$ / (mol.kg^{-1})	L_f /(Å)			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
0.30703	4.216716	4.2249668	4.244493	4.255476
0.39832	4.180071	4.1937154	4.2164982	4.227889
0.50431	4.144185	4.1573554	4.1862589	4.19638
PEG 600 + 0.01 m D-Mannitol				
0.00000	4.323352	4.3415140	4.3476247	4.356963
0.10007	4.229964	4.2445140	4.2516917	4.266001
0.19940	4.134455	4.1493170	4.1614274	4.179130
0.30387	4.037801	4.0545027	4.0700979	4.090286
0.40836	3.954440	3.9638203	3.9827109	4.005229
0.51045	3.868789	3.8772677	3.8993531	3.924925
PEG 600 + 0.03 m D-Mannitol				
0.00000	4.312992	4.3291704	4.3403678	4.347625
0.10164	4.217592	4.2300514	4.2449929	4.256822
0.19998	4.121949	4.1386341	4.1558683	4.170374
0.29836	4.040029	4.0491972	4.0681159	4.085706
0.40338	3.946724	3.9577385	3.9805289	4.000173
0.50796	3.859071	3.8696802	3.8944115	3.917887
PEG 600 + 0.05 m D-Mannitol				
0.00000	4.291631	4.3173727	4.3322391	4.341150
0.10321	4.191493	4.2171623	4.2344649	4.247381
0.20127	4.108078	4.1260187	4.1456628	4.161105
0.29925	4.016871	4.0374553	4.0585602	4.076669
0.40027	3.924967	3.9488397	3.9741969	3.993674
0.50798	3.842719	3.8583753	3.8845404	3.909618

Table 6. Values of Vander Waal's constant of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

$^{a}m_A$ / (mol.kg^{-1})	b/ (m^3 /mol)			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
PEG 200 + 0.01 m D-Mannitol				
0.00000	395.9098	396.3769	396.9057	397.5432
0.10160	394.8174	395.2842	395.8076	396.4425
0.20371	393.7253	394.1904	394.7100	395.3320
0.30012	392.6981	393.1603	393.6770	394.2962
0.40211	391.6189	392.0803	392.5919	393.2055
0.49810	390.6069	391.0629	391.5748	392.1853
PEG 200 + 0.03 m D-Mannitol				
0.00000	395.3517	395.8386	396.3342	396.9789
0.10516	394.2470	394.7381	395.2411	395.8850
0.20753	393.1789	393.6703	394.1783	394.8181
0.30249	392.1930	392.6848	393.1894	393.8314
0.41702	391.0107	391.5028	392.0096	392.6407
0.49987	390.1588	390.6514	391.1546	391.7900
PEG 200 + 0.05 m D-Mannitol				
0.00000	394.7952	395.3017	395.7644	396.4162
0.11021	393.6418	394.1520	394.6175	395.2664
0.20923	392.6116	393.1188	393.5862	394.2337
0.30703	391.5984	392.1051	392.5693	393.2171
0.39832	390.6582	391.1642	391.6251	392.2695
0.50431	389.5716	390.0785	390.5308	391.1753
PEG 600 + 0.01 m D-Mannitol				
0.00000	1186.888	1187.772	1189.901	1191.181
0.10007	1176.710	1179.081	1179.538	1181.906
0.19940	1166.906	1168.336	1170.174	1172.713
0.30387	1156.855	1158.392	1160.364	1163.109
0.40836	1146.701	1148.672	1150.840	1153.524
0.51045	1137.157	1139.079	1141.766	1144.436

$^{a}m_A$ / (mol.kg^{-1})	b/ (m^3 /mol)			
	T= 293.15 K	T=298.15 K	T= 303.15 K	T= 308.15 K
PEG 600 + 0.03 m D-Mannitol				
0.00000	1185.197	1186.489	1188.244	1189.521
0.10164	1175.072	1176.612	1178.503	1179.937
0.19998	1165.392	1167.116	1169.178	1170.753
0.29836	1155.857	1157.727	1159.793	1161.592
0.40338	1145.621	1147.893	1149.983	1151.759
0.50796	1135.730	1138.13	1140.572	1142.366
PEG 600 +0.05 m D-Mannitol				
0.00000	1180.641	1183.461	1186.483	1187.633
0.10321	1170.773	1173.542	1176.636	1178.056
0.20127	1161.339	1164.116	1167.161	1168.805
0.29925	1152.044	1154.716	1157.836	1159.545
0.40027	1142.478	1145.169	1148.197	1150.137
0.50798	1132.4	1135.115	1138.246	1140.072

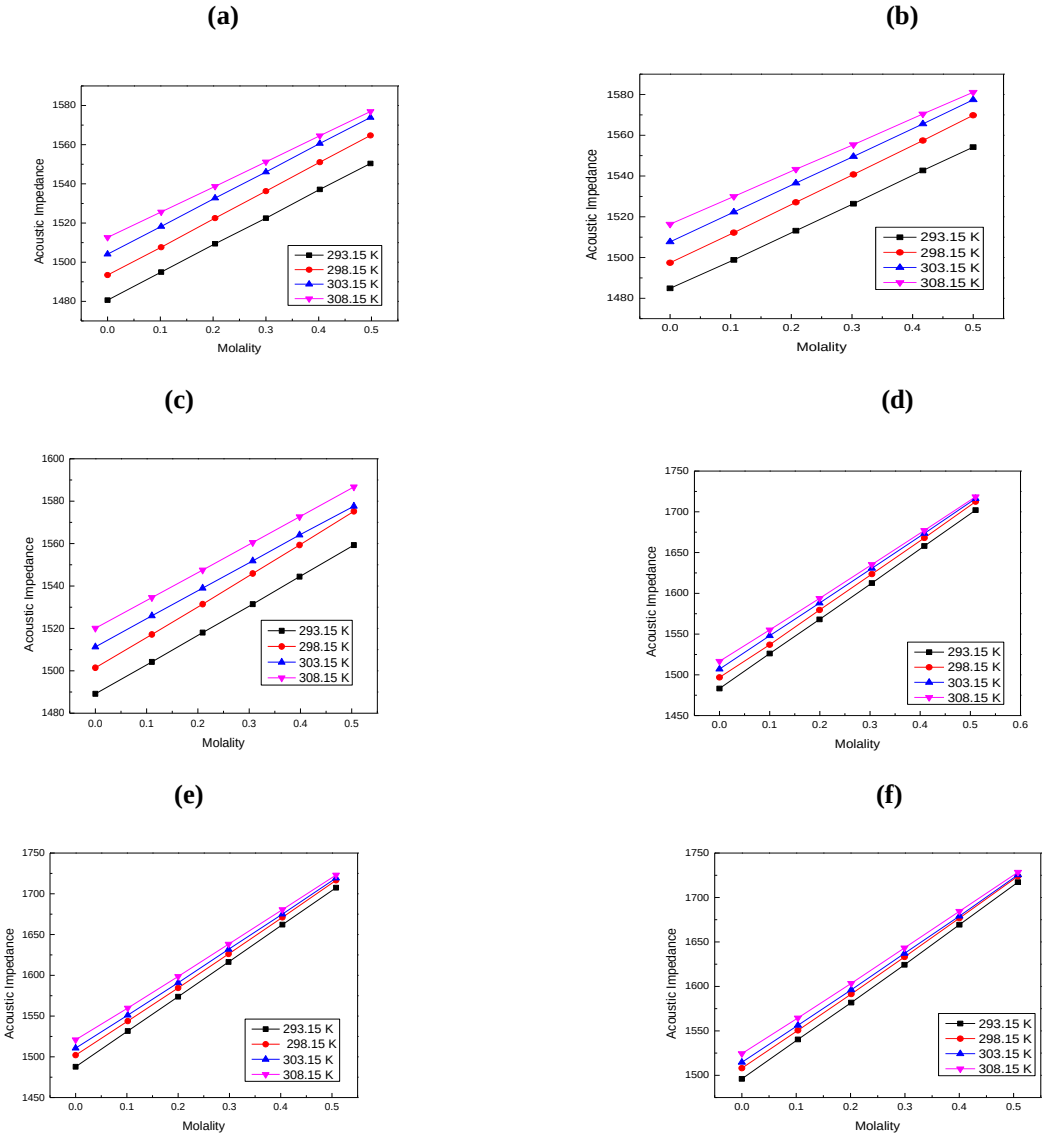


Figure 1. Variation of Acoustic Impedance, Z, of, PEG 200 (**a**) 0.01 D-Mannitol, (**b**) 0.03 D-Mannitol and (**c**) 0.05 D-Mannitol, and PEG 600 (**d**) 0.01 D-Mannitol, (**e**) 0.03 D-Mannitol and (**f**) 0.05 D-Mannitol at different temperature.

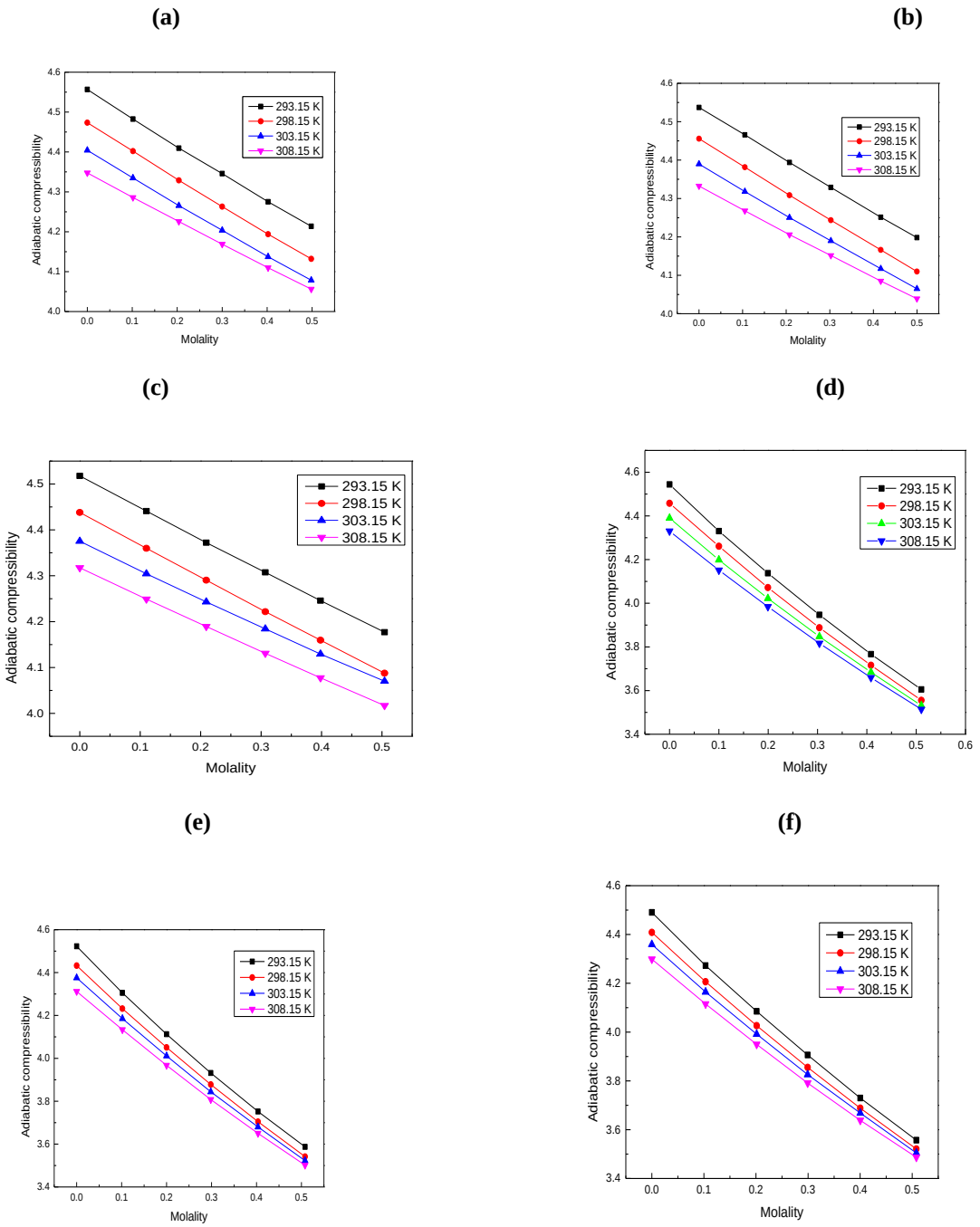
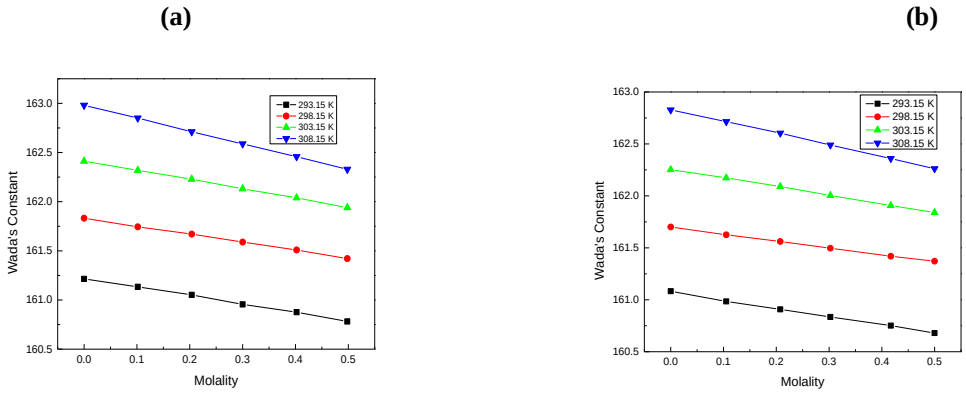


Figure 2. Variation of Adiabatic compressibility, β, of, PEG 200 (**a**) 0.01 D-Mannitol, (**b**) 0.03 D-Mannitol and (**c**) 0.05 D-Mannitol, and PEG 600 (**d**) 0.01 D-Mannitol, (**e**) 0.03 D-Mannitol and (**f**) 0.05 D-Mannitol at different temperature.



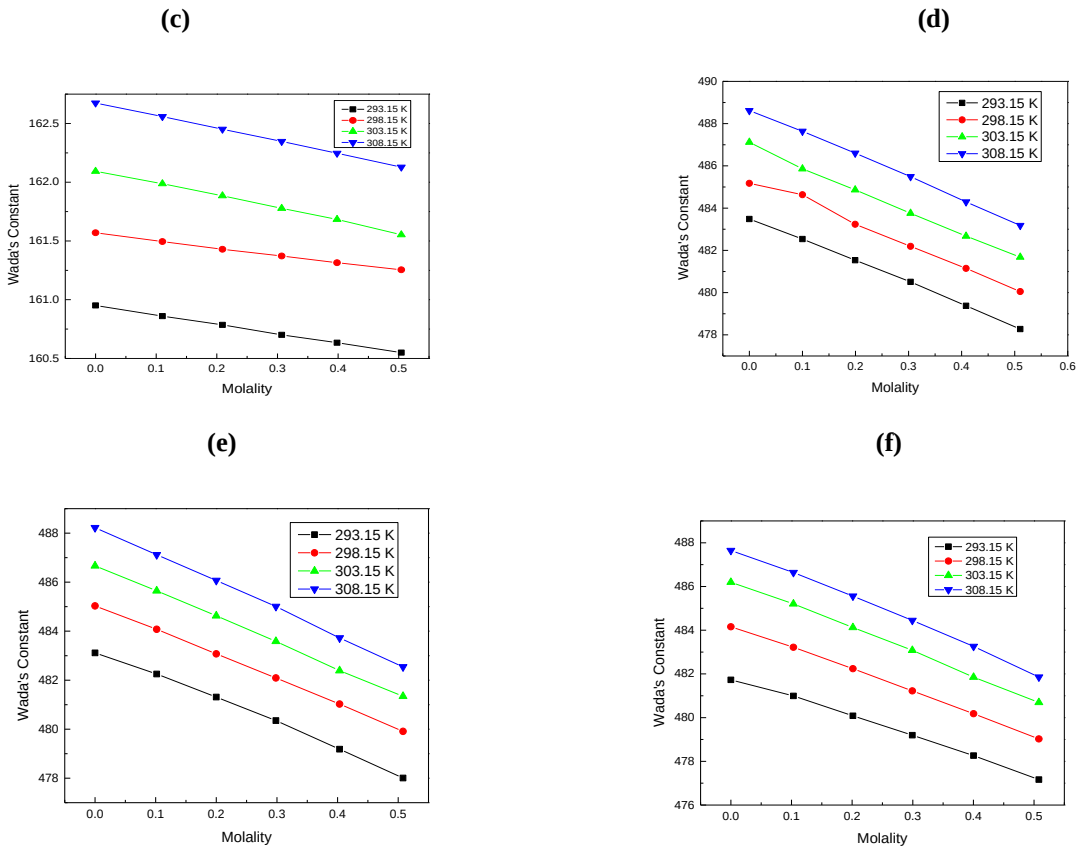
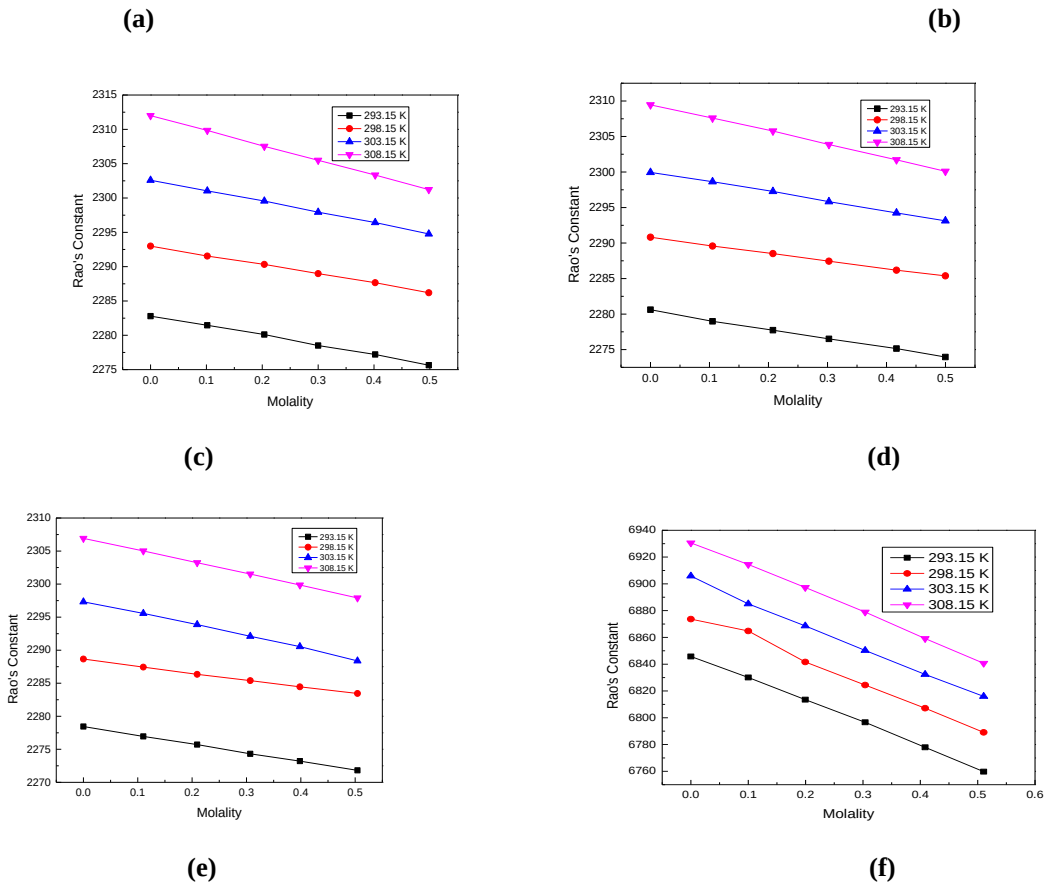


Figure 3. Variation of Wada constant, W, of, PEG 200 (**a**) 0.01 D-Mannitol, (**b**) 0.03 D-Mannitol and (**c**) 0.05 D-Mannitol, and PEG 600 (**d**) 0.01 D-Mannitol, (**e**) 0.03 D-Mannitol and (**f**) 0.05 D-Mannitol at different temperature.



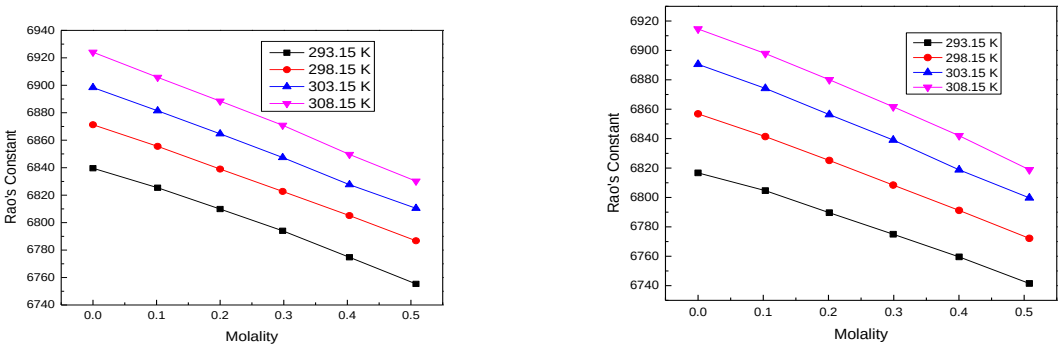


Figure 4. Variation of Rao constant of, PEG 200 (**a**) 0.01 D-Mannitol, (**b**) 0.03 D-Mannitol and (**c**) 0.05 D-Mannitol, and PEG 600 (**d**) 0.01 D-Mannitol, (**e**) 0.03 D-Mannitol and (**f**) 0.05 D-Mannitol at different temperature.

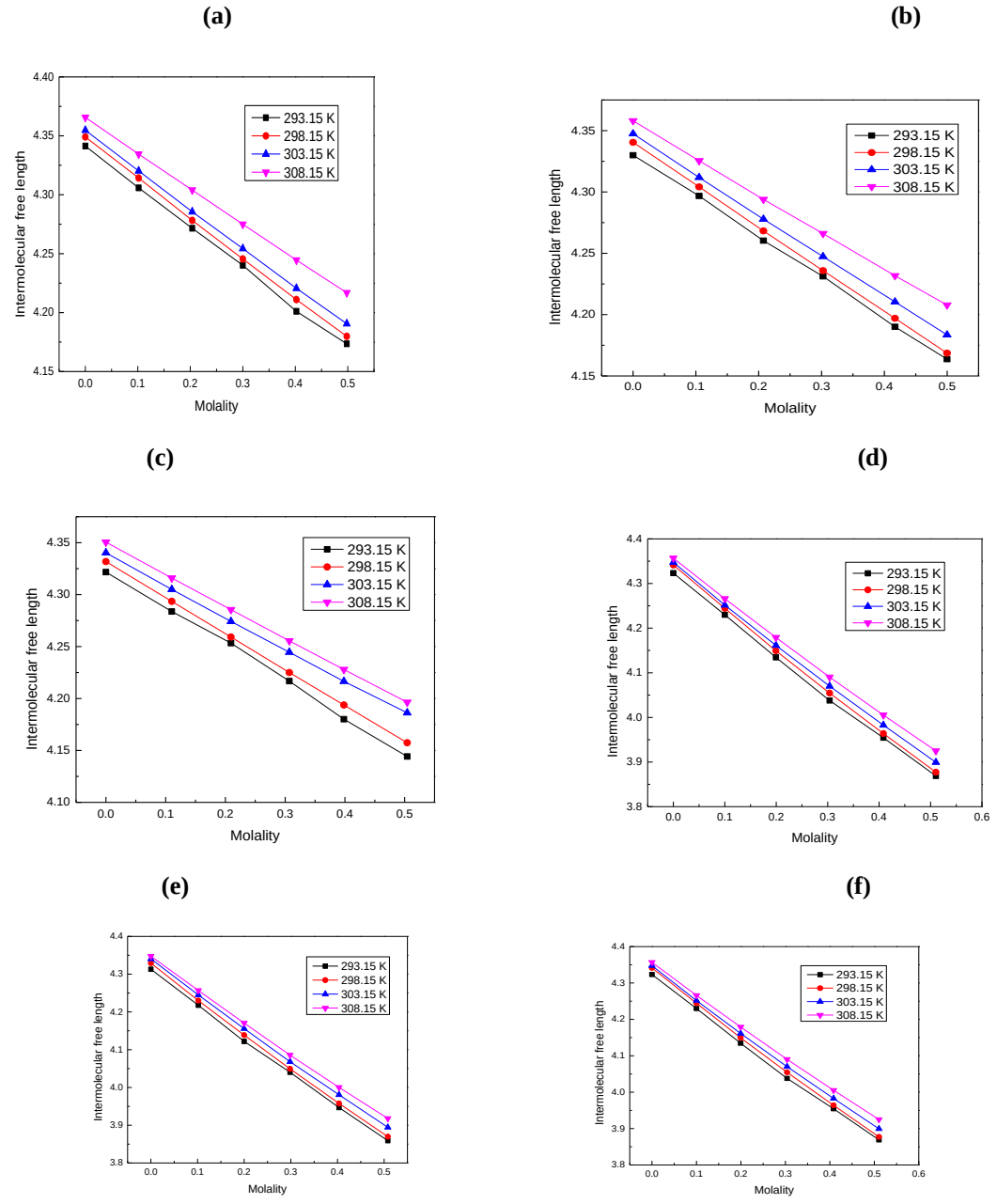


Figure 5. Variation intermolecular free length of, PEG 200 (**a**) 0.01 D-Mannitol, (**b**) 0.03 D-Mannitol and (**c**) 0.05 D-Mannitol, and PEG 600 (**d**) 0.01 D-Mannitol, (**e**) 0.03 D-Mannitol and (**f**) 0.05 D-Mannitol at different temperature.

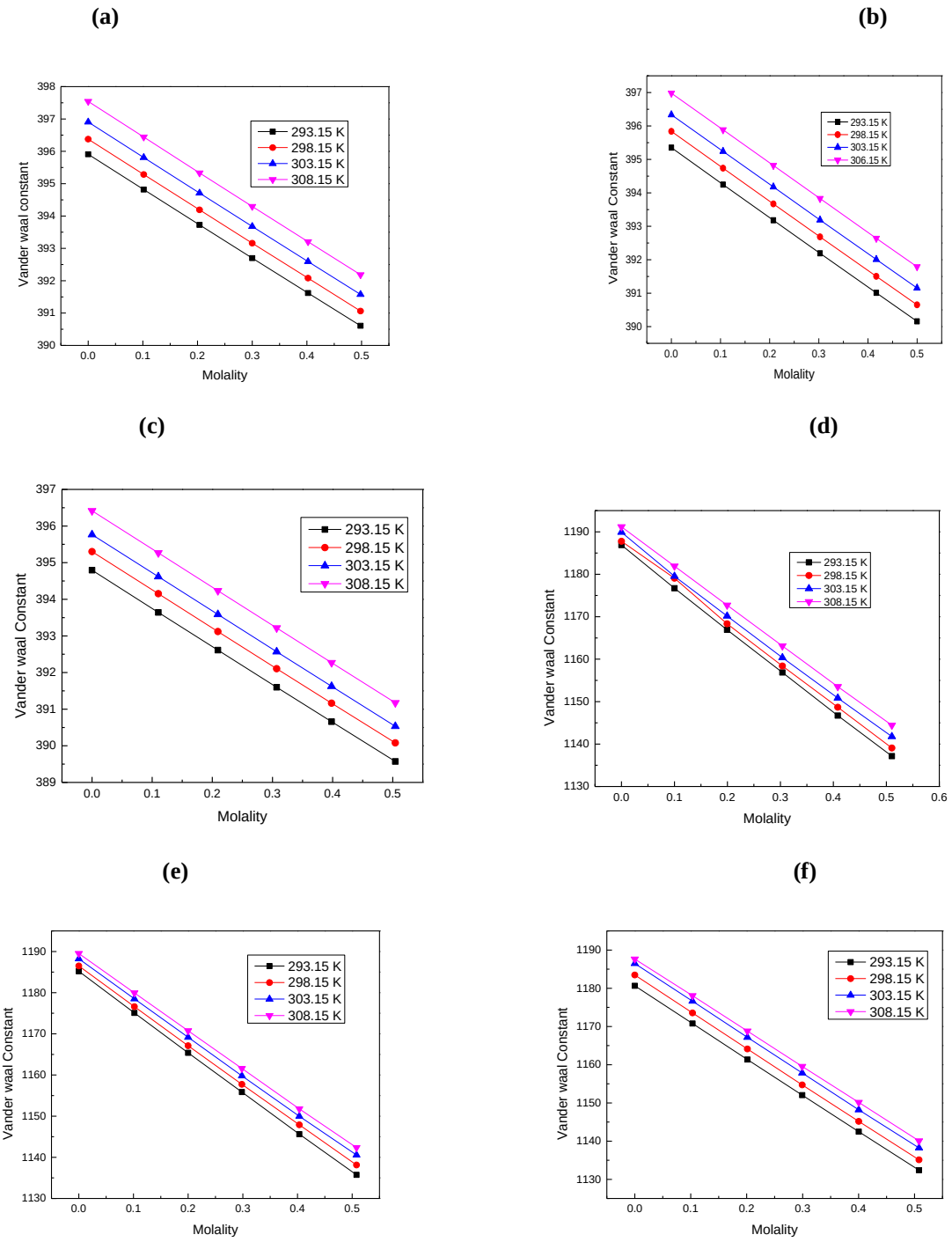


Figure 6. Variation of Vander Waal constant of, PEG 200(**a**) 0.01 D-Mannitol, (**b**) 0.03 D-Mannitol and (**c**) 0.05 D-Mannitol, and PEG 600 (**d**) 0.01 D-Mannitol, (**e**) 0.03 D-Mannitol and (**f**) 0.05 D-Mannitol at different temperature.

4. Conclusions

The experimentally obtained and derived parameters indicate the presence of molecular interaction between the polyethylene glycols and D-Mannitol solution. Additionally, it is concluded that molecular interactions increase with the increase in molar mass. So, polyethylene glycol with molar mass 600 shows stronger interaction than polyethylene glycol with molar mass 200. The derived parameters, such as intermolecular free length, acoustic impedance, adiabatic compressibility, Wada's constant, Rao's Constant, and Vander Waal's constant, show a linear trend. The linear trend of the parameters indicates the absence of

complex formation. Acoustic impedance shows the increasing linear trend with concentration and temperature. The values of adiabatic compressibility decrease with the increase in temperature and the concentration of D-Mannitol. Furthermore, values of Wada constant, Rao constant, intermolecular free length, and Vander Waal constant increase with the increase in temperature and decrease with increase in the concentration of D-mannitol.

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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.

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