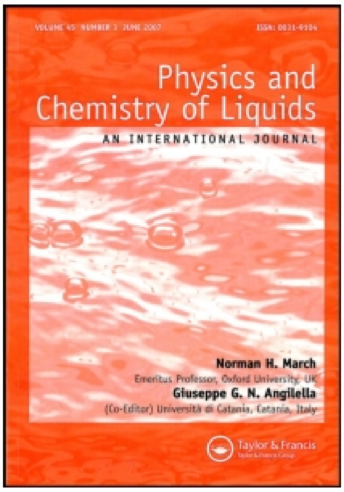

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Viscosities and excess viscosities of methanol, ethanol and *n*-propanol in pure water and in water + surf excel solutions at different temperatures

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Viscosities, η of the systems methanol, ethanol and *n*-propanol in water, and in 0.05% and 0.1% Surf Excel (SE) solutions were measured at temperatures 303.15, 308.15, 313.15, 318.15 and 323.15 K, respectively, covering the whole composition range. On addition of alcohols to water or water + SE systems, viscosities pass through the maxima and then decline continuously. The heights of the maxima occurring between 0.2 and 0.3 mole fraction of alcohols are in the order *n*-propanol > ethanol > methanol. Excess viscosities, η^E for the systems were found to be positive. For all alcohols, excess viscosities show a maxima in the water-rich region. All these properties have been expressed satisfactorily by appropriate polynomials. No appreciable change in the viscosities and excess viscosities were observed by the addition of surfactant (0.05% and 0.1%) to the studied systems. An explanation of η^E in terms of hydrophobic hydration and hydrophilic effect of the solutes is offered.

Keywords: Excess viscosities; Methanol; Ethanol and *n*-Propanol; Surfactants

1. Introduction

Various excess properties like excess volume, excess viscosity etc. are quite useful in the study of molecular interactions in binary and ternary liquid mixtures. Both alcohols and water are self-associated liquids through H-bonding. Interactions between water and alcohols are extremely complex. Alcohols possess hydrophilic OH group as well as the hydrophobic group. The mode of interaction of these two groups towards water is completely different. The hydrophilic OH group

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of an alcohol forms H-bond with water through hydrophilic interactions and disrupts the normal water structure, while the alkyl group promotes the structure of water molecules surrounding this group, through hydrophobic hydration. A better understanding of the water–alcohol interaction is of vital importance in the field of solution chemistry, as it can provide important information regarding hydrophilic and hydrophobic interactions. It is believed that both the hydrophilic and hydrophobic effects take place in water-rich region of aqueous alcohol solutions. Recently, we reported the densities and excess molar volumes of alcohols in water + SE solution [1] and the volumetric and viscometric properties of carbohydrates in water + SE [2] and the electrolytes in water + SDS [3] systems. Micelle formation of surfactant molecules in water solution is a typical hydrophobic process [4]. In water medium, surfactant molecules with their long hydrophobic tails undergo hydrophobic hydration. By increasing the concentration of the surfactant, an abrupt change in several physico-chemical properties of the solution, such as osmotic pressure, electrical conductance, surface tension, viscosity, molar volume etc. is observed. Here, we report the effect of some simple alcohols on the structure of water or water + SE systems based on viscometric measurements only. Micelle-forming molecules in SE may force water to be in a certain structural form in the water + SE system. The perturbations of this forced structure in water + SE system by some alcohols are expected to be more appreciable than the perturbation caused by these alcohols in only the water system. The knowledge of interactions of simple smaller hydrophobic molecules with water and with water + surfactant solvent systems may be useful sometimes to interpret many complex systems [5]. The data are also useful for the design of mixing, storage and process equipment.

2. Experimental

2.1. *Materials*

The chemicals used were procured from Aldrich Chemical Co. with the quoted purities: Methanol (99.5%), Ethanol (99.0%) and *n*-Propanol (99.5%). Surf Excel, a commercial detergent powder was procured from a local market at Rajshahi, Bangladesh. These chemicals were used without any further purification.

2.2. *Viscosity measurements*

The densities were measured by using 5-mL bicapillary pycnometers. The volumes of the pycnometers were calibrated with deionized and doubly distilled water at 303.15, 308.15, 313.15, 318.15 and 323.15 K. The densities of solutions in water and water + SE solutions were determined from the mass of the solution in the pycnometer, after reaching thermal equilibrium in a water bath at the studied temperatures. A Mettler PM–200 electronic balance with an accuracy of ± 0.0001 g was used for the determination of mass. The viscosities were measured by a calibrated U-type Ostwald viscometer of the British standard institution, with a sufficiently long efflux time to avoid kinetic energy correction. The provided calibration constants were checked with water, ethanol, and *n*-hexane. Temperatures were controlled by a thermostatic water bath with fluctuations upto ±0.01°C. The viscosity, η of the solutions was calculated by

$$\eta = A\rho t \tag{1}$$

where t is the flow time, ρ is the density of the solution, and A is the viscometer constant. The uncertainty in the measurement of viscosity was ±0.1%.

2.3. *Determination of excess viscosities*

The excess viscosities, η^E were calculated using the following equation:

$$\eta^E = \eta_{obs} - \eta_{id} \tag{2}$$

where, η_{obs} is the observed viscosity. The ideal viscosity of mixture, η_{id} may be represented as:

$$\ln \eta_{id} = X_1 \ln \eta_1 + X_2 \ln \eta_2 \tag{3}$$

The excess viscosities, η^E were fitted to a Redlich–Kister polynomial equation of the form,

$$\eta^E = X_1 X_2 \sum_{i=0}^{n} a_i (1 - 2X_1)^i \tag{4}$$

where a_i is the ith fitting coefficient. Using $n = 3$, four a_i coefficients and the standard deviation σ were obtained through the least squares method.

3. Results and discussion

The viscosities of methanol, ethanol and *n*-propanol in water and 0.05% and 0.1% SE solutions in water were determined at 303.15, 308.15, 313.15, 318.15 and 323.15 K, over the entire composition range. The viscosities of the pure components are shown in table 1, together with the literature values for methanol and ethanol

Table 1. Density d ($g\,cm^{-3}$) and viscosity (cP) of pure liquids.

T/K	Methanol	Ethanol	Propanol
303.15	0.5146	1.1808	1.7466
	0.5232[7]	1.0102[7]	1.7354[6]
			1.7309[7]
308.15	0.4837	1.0638	1.5422
			1.5484[6]
313.15	0.4542	0.9646	1.3897
			1.3859[6]
318.15	0.4256	0.8714	1.2440
			1.2455[6]
323.15	0.3983	0.8010	1.10911
			1.1208[6]

only at 303.15 K and for propanol at 303.15–323.15 K, wherever possible for comparison. The agreement between the measured values and the literature values is satisfactory.

The viscosities of the binary and ternary systems have been shown in tables 2–4, at different temperatures. The variation of viscosities at these temperatures as a function of the mole fraction of the alcohols is shown in figures 1–9. The viscosities increase rapidly with an increase in alcohol concentration and show a maxima in the water-rich region (0.2–0.3 mole fraction of alcohol) and then a regular decrease in viscocity. The position of the maxima virtually does not change remarkably with the variation of temperature.

The excess viscosities η^E of the systems are shown in tables 2–4. The values of the fitting parameters, along with the standard deviation, are presented in tables 5–7. Figures 10–12 represent the η^E *versus* the X_2 curves at 303.15 K for all the systems. The η^E values are positive and large in magnitude, which demonstrate that the aqueous solutions of alcohols are highly non-ideal. All the curves pass through the maxima in the water-rich region. The height and the sharpness of the maxima are in the order

n-Propanol > Ethanol > Methanol

The viscosities and the excess viscosities are accounted for mainly by the following factors:

1. Strong alcohol–water and alcohol–alcohol interactions.
2. Hydrophobic hydration of alcohols.

The rapidly ascending portion of the viscosity curves (figures 1–9) in the dilute region of alcohol can be explained primarily in terms of the phenomenon called hydrophobic hydration. It can be assumed that in water-rich regions, the water molecule forms highly ordered structures through hydrogen bonding around the hydrocarbon moieties of alcohol. These are variously known as ice-bergs, clusters or cages. There is a large body of experimental evidences, which suggest the existence of such cages. On addition of alcohol to water, cages are formed continuously till the water molecules necessary to form the cages fall short. Concurrently, the hydroxyl groups of alcohol form hydrogen bonds with the surrounding water molecules.

The increase in viscosity with the mole fraction of alcohol in the water-rich region may be attributed to these two effects, collectively. After attaining the state of maximum viscosity further addition of alcohol continuously breaks down both the cages and alcohol–water associates, and instead, the alcohol–alcohol associates are preferentially formed, which result in the regular decrease in viscosity. The appearance of viscosity maxima is therefore expected as a result of these competing processes [6,8]. This interpretation seems to explain well the viscosity composition curves for all the alcohols studied.

The effect of the addition of surfactant (SE) to alcohol systems has also been studied. Only very dilute solutions of SE (0.05% and 0.1% in water) were used due to its limited solubility. Figures 3 and 4 show the plots of viscosities as a function of mole fraction of methanol, ethanol, and *n*-propanol in 0.05% and 0.1% SE

Table 2. Viscosities, η (cP), excess viscosities, η^E (cP) of methanol in H_2O, 0.05% aqueous SE and 0.1% aqueous SE systems at 303.15, 308.15, 313.15, 318.15 and 323.15 K.

T/K	303.15		308.15		313.15		318.15		323.15	
X_2	η	η^E	η	η^E	η	η^E	η	η^E	η	η^E
					Water + Methanol Systems					
0.0000	0.8007	0.0000	0.7225	0.0000	0.6560	0.0000	0.5988	0.0000	0.5494	0.0000
0.0597	0.9910	0.2112	0.8870	0.1816	0.7907	0.1489	0.7095	0.1228	0.6414	0.1024
0.1280	1.2147	0.4581	1.0805	0.3942	0.9553	0.3295	0.8543	0.2811	0.7673	0.2401
0.2086	1.3489	0.6187	1.1966	0.5321	1.0596	0.4520	0.9406	0.3830	0.8412	0.3275
0.3041	1.3644	0.6644	1.2102	0.5707	1.0791	0.4925	0.9562	0.4165	0.8546	0.3564
0.4203	1.2317	0.5668	1.0987	0.4883	0.9738	0.4117	0.8652	0.3464	0.7757	0.2958
0.5657	1.0845	0.4610	0.9867	0.4109	0.8887	0.3559	0.8037	0.3101	0.7305	0.2725
0.7522	0.8309	0.2567	0.7684	0.2341	0.7020	0.2045	0.6437	0.1805	0.5916	0.1603
1.0000	0.5146	0.0000	0.4837	0.0000	0.4542	0.0000	0.4256	0.0000	0.3983	0.0000
					0.05% aqueous SE + Methanol systems					
0.0000	0.8030	0.0000	0.7229	0.0000	0.6569	0.0000	0.6024	0.0000	0.5498	0.0000
0.0601	0.9959	0.2141	0.8902	0.1845	0.7290	0.0865	0.7103	0.1203	0.6378	0.0985
0.1134	1.2125	0.4490	1.0787	0.3880	0.9501	0.3201	0.7851	0.2060	0.7540	0.2239
0.2101	1.3524	0.6211	1.1979	0.5335	1.0495	0.4416	0.9333	0.3733	0.7646	0.2508
0.3059	1.3690	0.6682	1.2132	0.5739	1.0685	0.4817	0.8818	0.3401	0.8442	0.3460
0.4425	1.2228	0.5633	1.0768	0.4717	0.9493	0.3914	0.8457	0.3291	0.7574	0.2807
0.5700	1.0903	0.4672	0.9793	0.4044	0.8786	0.3463	0.7945	0.3003	0.7222	0.2647
0.7551	0.8359	0.2621	0.7664	0.2327	0.6974	0.2002	0.6393	0.1762	0.6057	0.1747
1.0000	0.5146	0.0000	0.4837	0.0000	0.4542	0.0000	0.4256	0.0000	0.3983	0.0000
					0.1% aqueous SE + Methanol systems					
0.0000	0.8042	0.0000	0.7268	0.0000	0.6606	0.0000	0.6022	0.0000	0.5530	0.0000
0.0597	1.0254	0.2424	0.9102	0.2009	0.8168	0.1708	0.7358	0.1459	0.6693	0.1270
0.1280	1.2340	0.4745	1.0895	0.3996	0.9667	0.3370	0.8634	0.2879	0.7757	0.2454
0.2098	1.3655	0.6332	1.1985	0.5312	1.0618	0.4511	0.9432	0.3833	0.8411	0.3249
0.3070	1.3745	0.6733	1.2191	0.5777	1.0825	0.4937	0.9570	0.4157	0.8600	0.3600
0.4235	1.2894	0.6237	1.1514	0.5397	1.0281	0.4644	0.9181	0.3982	0.8273	0.3461
0.5698	1.0903	0.4667	0.9850	0.4087	0.8869	0.3533	0.8051	0.3110	0.7309	0.2722
0.7557	0.8208	0.2469	0.7601	0.2258	0.6942	0.1965	0.6357	0.1724	0.5827	0.1848
1.0000	0.5146	0.0000	0.4837	0.0000	0.4542	0.0000	0.4256	0.0000	0.3983	0.0000

Table 3. Viscosities, η (cP), excess viscosities, η^E (cP) of ethanol in H_2O, 0.05% aqueous SE and 0.1% aqueous SE systems at 303.15, 308.15, 313.15, 318.15 and 323.15 K.

T/K	303.15		308.15		313.15		318.15		323.15	
X_2	η	η^E	η	η^E	η	η^E	η	η^E	η	η^E
Water + Ethanol Systems										
0.0000	0.8007	0.0000	0.7225	0.0000	0.6560	0.0000	0.5988	0.0000	0.5494	0.0000
0.0950	1.4609	0.6301	1.2539	0.5044	1.0838	0.4033	0.9470	0.3265	0.8377	0.2683
0.1722	1.8839	1.0278	1.6100	0.8378	1.3860	0.6837	1.2051	0.5663	1.0516	0.4653
0.2382	1.9930	1.1147	1.7066	0.9144	1.4742	0.7531	1.2781	0.6233	1.1255	0.5245
0.3661	1.9425	1.0194	1.6777	0.8453	1.4625	0.7071	1.2763	0.5893	1.1206	0.4899
0.4821	1.7387	0.7731	1.5040	0.6334	1.3050	0.5750	1.1367	0.4192	0.9981	0.3392
0.6358	1.5963	0.5713	1.4097	0.4857	1.2476	0.4094	1.1083	0.3482	0.9908	0.2926
0.7918	1.4012	0.3121	1.2540	0.2725	1.1186	0.2284	1.0021	0.1962	0.9026	0.1629
1.0000	1.1808	0.0000	1.0638	0.0000	0.9646	0.0000	0.8714	0.0000	0.8010	0.0000
0.05% aqueous SE + Ethanol systems										
0.0000	0.8030	0.0000	0.7229	0.0000	0.6569	0.0000	0.6024	0.0000	0.5498	0.0000
0.0949	1.4707	0.6378	1.2581	0.5082	1.0899	0.4065	0.9503	0.3264	0.8380	0.2682
0.1729	1.9009	1.0425	1.6220	0.8492	1.3932	0.6872	1.2099	0.5678	1.0640	0.4772
0.2386	1.0070	1.1266	1.7185	0.9258	1.4756	0.7499	1.2888	0.6309	1.1263	0.5249
0.3680	1.9572	1.0318	1.6820	0.8487	1.4621	0.6962	1.2770	0.5869	1.1224	0.4909
0.4850	1.7597	0.7916	1.5051	0.6332	1.3052	0.5010	1.1366	0.4161	0.9984	0.3385
0.6401	1.6140	0.5862	1.4136	0.4879	1.2508	0.3928	1.1114	0.3484	0.9926	0.2931
0.7945	1.4196	0.3288	1.2568	0.2742	1.1211	0.2060	1.0076	0.1999	0.9060	0.1646
1.0000	1.1808	0.0000	1.0638	0.0000	0.9970	0.0000	0.8714	0.0000	0.8010	0.0000
0.1% aqueous SE + Ethanol systems										
0.0000	0.8042	0.0000	0.7268	0.0000	0.6606	0.0000	0.6022	0.0000	0.5530	0.0000
0.0948	1.4652	0.6312	1.2570	0.5035	1.0872	0.4003	0.9473	0.3236	0.8355	0.2627
0.1734	1.9071	1.0475	1.6305	0.8541	1.4016	0.6921	1.2165	0.5745	1.0676	0.4779
0.2386	2.0135	1.1321	1.7255	0.9295	1.4821	0.7532	1.2946	0.6369	1.1304	0.5263
0.3684	1.9630	1.0366	1.6889	0.8526	1.4679	0.6991	1.2805	0.5905	1.1268	0.4929
0.4854	1.7516	0.7826	1.5142	0.6398	1.3240	0.5173	1.1559	0.4354	1.0160	0.3540
0.6400	1.6052	0.5769	1.4180	0.4905	1.2544	0.3947	1.1137	0.3508	0.9947	0.2937
0.7946	1.4061	0.3149	1.2607	0.2770	1.1227	0.2065	1.0057	0.1980	0.9036	0.1613
1.0000	1.1808	0.0000	1.0638	0.0000	0.9970	0.0000	0.8714	0.0000	0.8010	0.0000

Table 4. Viscosities, η (cP), excess viscosities, η^E (cP) of *n*-propanol in H_2O, 0.05% aqueous SE and 0.1% aqueous SE systems at 303.15, 308.15, 313.15, 318.15 and 323.15 K.

T/K	303.15		308.15		313.15		318.15		323.15	
X_2	η	η^E	η	η^E	η	η^E	η	η^E	η	η^E
Water + *n*-Propanol Systems										
0.0000	0.8007	0.0000	0.7225	0.0000	0.6560	0.0000	0.5988	0.0000	0.5494	0.0000
0.0738	1.5339	0.6858	1.3091	0.5448	1.1322	0.4388	0.9864	0.3544	0.8639	0.2853
0.1925	2.1906	1.2602	1.8801	1.0435	1.6258	0.8678	1.4174	0.7281	1.2403	0.6113
0.3067	2.2772	1.2601	1.9670	1.0544	1.7057	0.8799	1.4916	0.7423	1.3043	0.6228
0.4143	2.2132	1.1071	1.9121	0.9216	1.6650	0.7697	1.4567	0.6460	1.2751	0.5401
0.5764	1.9685	0.7133	1.6946	0.5740	1.4799	0.4687	1.2884	0.3757	1.1225	0.2989
0.6817	1.9508	0.5882	1.7043	0.4901	1.5119	0.4176	1.3370	0.3513	1.1821	0.2952
0.8190	1.8418	0.3252	1.6223	0.2743	1.4466	0.2335	1.2881	0.1983	1.1436	0.1669
1.0000	1.7466	0.0000	1.5422	0.0000	1.3897	0.0000	1.2440	0.0000	1.1091	0.0000
0.05% aqueous SE + *n*-Propanol systems										
0.0000	0.8030	0.0000	0.7229	0.0000	0.6569	0.0000	0.6024	0.0000	0.5498	0.0000
0.0740	1.5237	0.6732	1.3290	0.5642	1.1393	0.4449	0.9836	0.3480	0.8672	0.2880
0.1933	2.1684	1.2353	1.8756	1.0382	1.6239	0.8646	1.4054	0.7124	1.2374	0.6077
0.3079	2.2631	1.2430	1.9681	1.0543	1.7083	0.8809	1.4822	0.7291	1.3042	0.6218
0.4174	2.1963	1.0856	1.9082	0.9150	1.6661	0.7679	1.4486	0.6333	1.7259	0.5390
0.5762	1.9580	0.7015	1.7055	0.5848	1.4786	0.4669	1.2963	0.3814	1.1302	0.3064
0.6823	1.9393	0.5748	1.7154	0.5005	1.5110	0.4155	1.3445	0.3565	1.1880	0.3005
0.8195	1.8216	0.3036	1.6243	0.2757	1.4395	0.2254	1.2891	0.1977	1.1436	0.1665
1.0000	1.7466	0.0000	1.5472	0.0000	1.3900	0.0000	1.2440	0.0000	1.1091	0.0000
0.1% aqueous SE + *n*-Propanol systems										
0.0000	0.8042	0.0000	0.7268	0.0000	0.6606	0.0000	0.6022	0.0000	0.5530	0.0000
0.0745	1.5513	0.6993	1.3267	0.5578	1.1367	0.4385	0.9977	0.3621	0.8755	0.2931
0.1931	2.1872	1.2531	1.8752	1.0342	1.6116	0.8490	1.4164	0.7236	1.2397	0.6072
0.3079	2.2797	1.2586	1.9656	1.0484	1.6939	0.8633	1.4922	0.7393	1.3049	0.6197
0.4181	2.2115	1.0993	1.9101	0.9133	1.6536	0.7520	1.4557	0.6401	1.2759	0.5361
0.5761	1.9776	0.7204	1.7173	0.5941	1.4849	0.4708	1.3021	0.3874	1.1462	0.3204
0.6831	1.9570	0.5910	1.7217	0.5039	1.5065	0.4084	1.3345	0.3460	1.1875	0.2979
0.8197	1.8534	0.3347	1.6318	0.2816	1.4381	0.2226	1.2810	0.1895	1.1437	0.1654
1.0000	1.7466	0.0000	1.5472	0.0000	1.3900	0.0000	1.2440	0.0000	1.1091	0.0000

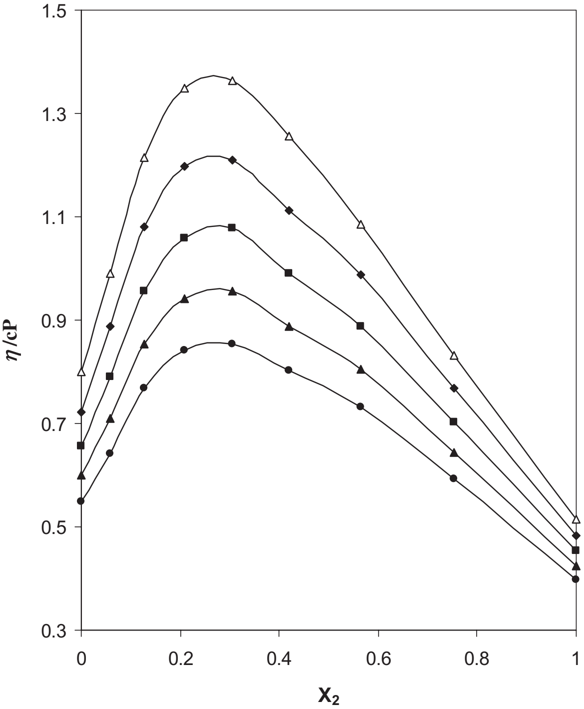

Figure 1. Plots of viscosity (η) *vs.* X_2 for methanol in system at △, 303.15 K; ◆, 308.15 K; ■, 313.15 K; ▲, 318.15 K; ●, 323.15 K.

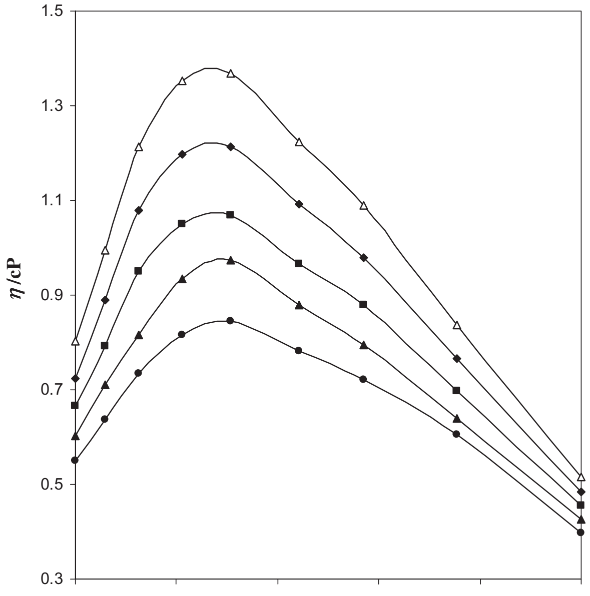

Figure 2. Plots of viscosity (η) *vs.* X_2 for methanol in aqueous 0.05% SE systems at △, 303.15 K; ◆, 308.15 K; ■, 313.15 K; ▲, 318.15 K; ●, 323.15 K.

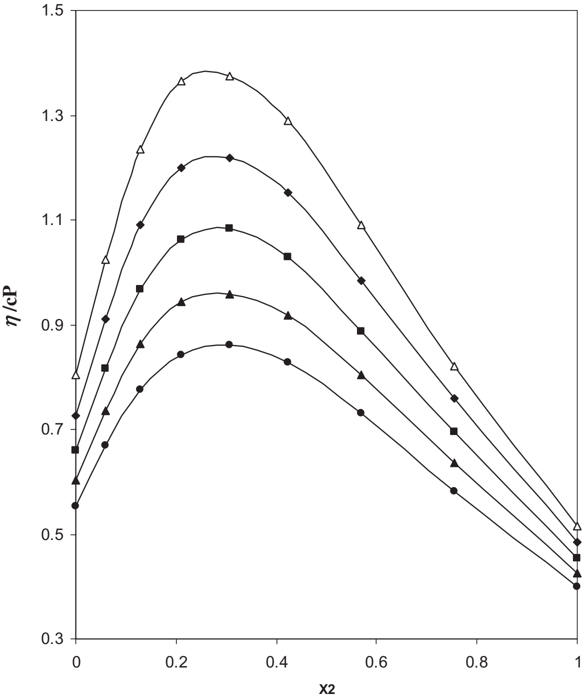

Figure 3. Plots of viscosity (η) *vs.* X_2 for methanol in aqueous 0.1% SE systems at △, 303.15 K; ◆, 308.15 K; ■, 313.15 K; ▲, 318.15 K; ●, 323.15 K.

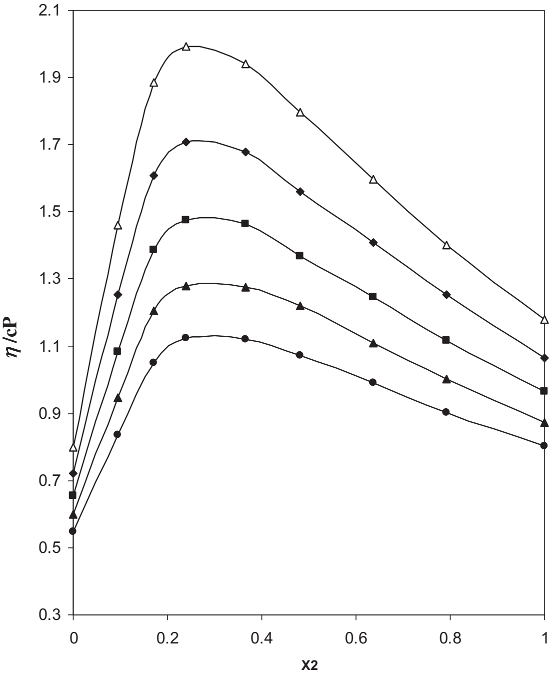

Figure 4. Plots of viscosity (η) *vs.* X_2 for ethanol in aqueous systems at △, 303.15 K; ◆, 308.15 K; ■, 313.15 K; ▲, 318.15 K; ●, 323.15 K.

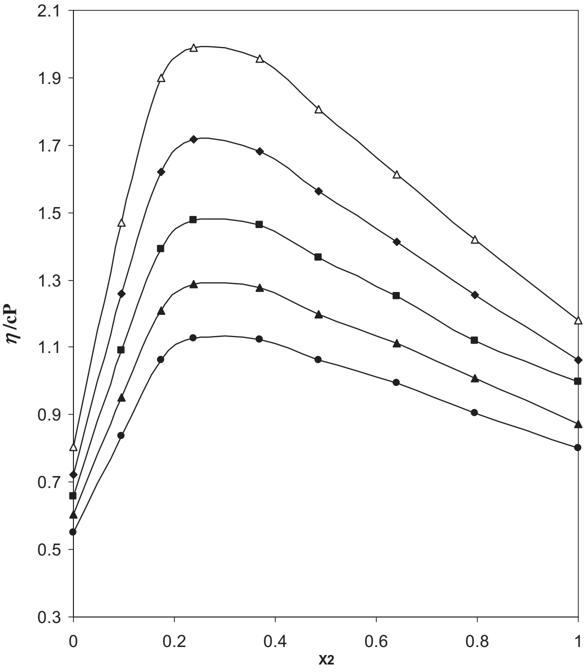

Figure 5. Plots of viscosity (η) *vs.* X_2 for ethanol in aqueous 0.05% SE systems at △, 303.15 K; ◆, 308.15 K; ■, 313.15 K; ▲, 318.15 K; ●, 323.15 K.

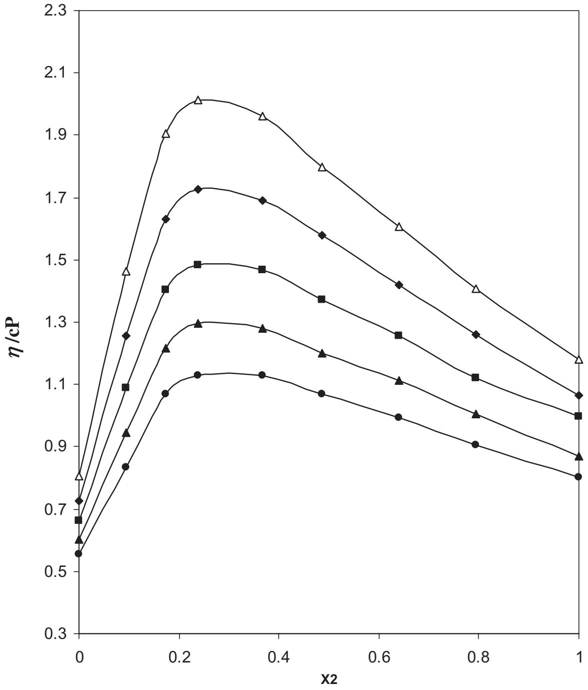

Figure 6. Plots of viscosity (η) *vs.* X_2 for ethanol in aqueous 0.1% SE systems at △, 303.15 K; ◆, 308.15 K; ■, 313.15 K; ▲, 318.15 K; ●, 323.15 K.

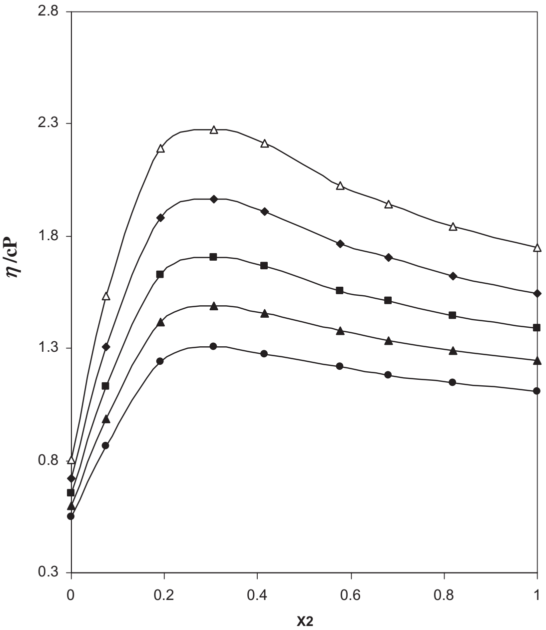

Figure 7. Plots of viscosity (η) *vs.* X_2 for *n*-propanol in aqueous at △, 303.15 K; ◆, 308.15 K; ■, 313.15 K; ▲, 318.15 K; ●, 323.15 K.

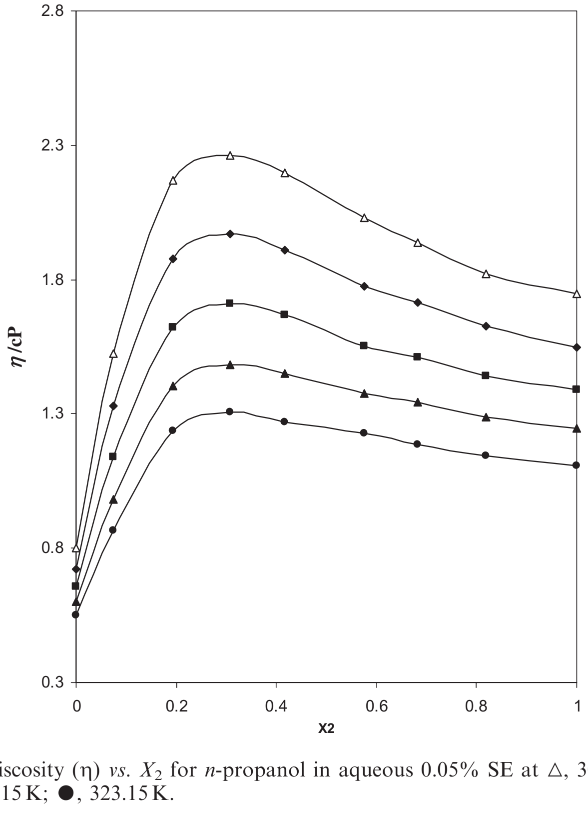

Figure 8. Plots of viscosity (η) *vs.* X_2 for *n*-propanol in aqueous 0.05% SE at △, 303.15 K; ◆, 308.15 K; ■, 313.15 K; ▲, 318.15 K; ●, 323.15 K.

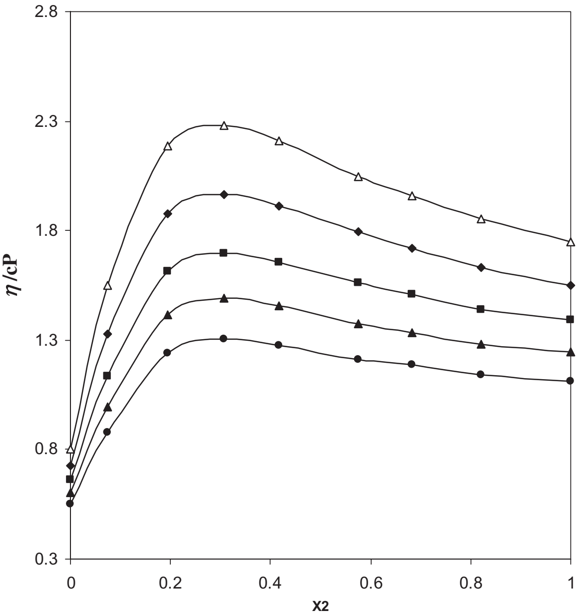

Figure 9. Plots of viscosity (η) *vs.* X_2 for *n*-propanol in aqueous 0.1% SE Systems at △, 303.15 K; ◆, 308.15 K; ■, 313.15 K; ▲, 318.15 K; ●, 323.15 K.

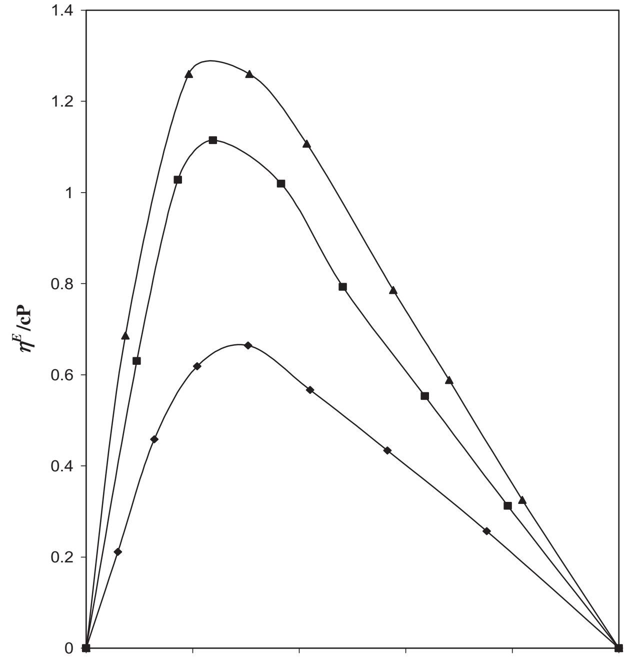

Figure 10. Plots of excess viscosity (η^E) *vs.* X_2 for methanol, ◆; ethanol, ■ and *n*-propanol, ▲ in aqueous systems at 303.15 K.

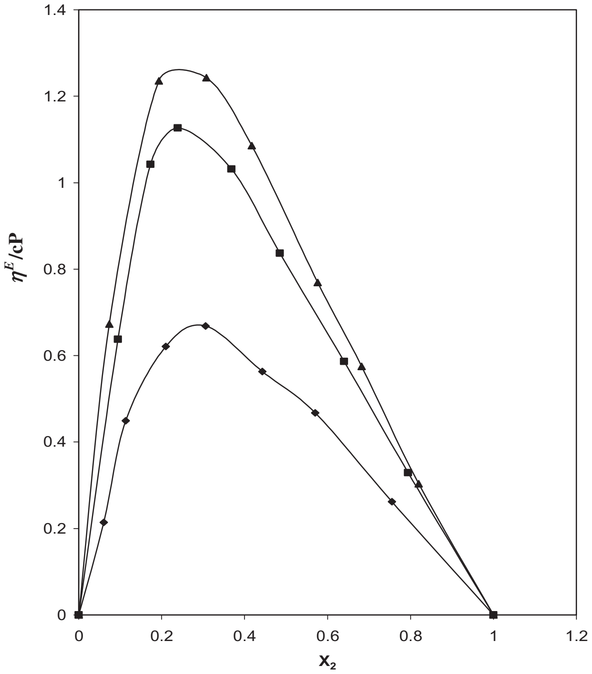

Figure 11. Plots of excess viscosity (η^E) *vs.* X_2 for methanol, ◆; ethanol, ■ and *n*-propanol, ▲ in 0.05% aqueous SE systems at 303.15 K.

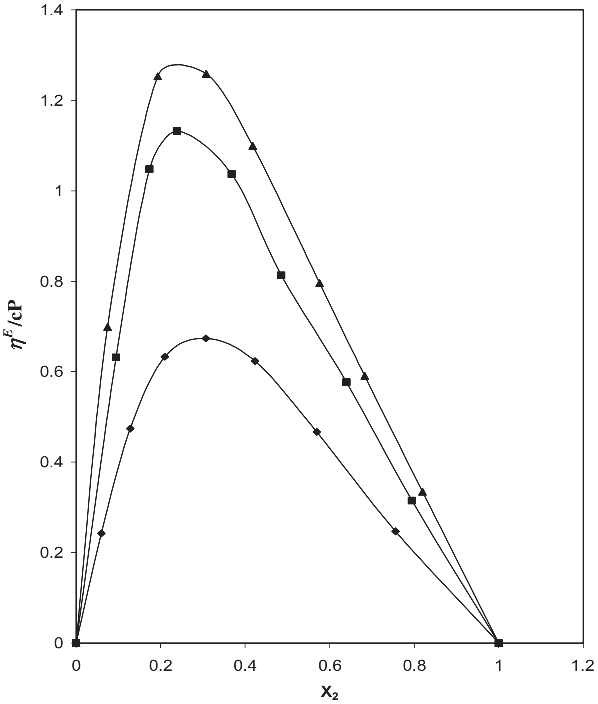

Figure 12. Plots of excess viscosity (η^E) *vs.* X_2 for methanol, ◆; ethanol, ■ and *n*-propanol, ▲ in 0.1% aqueous SE systems at 303.15 K.

Table 5. Coefficient, a_i, of Redlich–Kister equation (2) expressing η^E in cP and standard deviation, σ for the methanol systems.

Systems	T/K	a_0	a_1	a_2	a_3	σ
Water + methanol systems	303.15	2.0901	−2.3748	1.3158	1.3793	0.0225
	308.15	1.8408	−1.9260	1.0931	1.0301	0.0200
	313.15	1.6016	−1.6867	0.8788	1.1047	0.0161
	318.15	1.3909	−1.3821	0.6926	0.8850	0.0143
	323.15	1.2028	−1.1288	0.5941	0.7138	0.0145
0.05% Aqueous SE + methanol systems	303.15	2.1464	−2.2869	1.2547	0.9872	0.0250
	308.15	1.8460	−1.9195	1.1481	0.8348	0.0222
	313.15	1.5750	−1.6251	0.8845	0.9329	0.0235
	318.15	1.3558	−1.3926	0.7147	1.0400	0.0135
	323.15	1.1822	−0.9674	0.4026	0.8283	0.0097
0.1% Aqueous SE + methanol systems	303.15	2.1889	−2.3409	1.0057	0.6839	0.0105
	308.15	1.9061	−1.9354	0.8365	0.7013	0.0077
	313.15	1.6448	−1.6277	0.6704	0.6039	0.0055
	318.15	1.4280	−1.2754	0.4868	0.2606	0.0061
	323.15	1.2626	−1.1550	−0.2472	−0.4466	0.0053

Table 6. Coefficient, a_i, of Redlich–Kister equation (2) expressing η^E in cP and standard deviation, σ for the ethanol systems.

Systems	T/K	a_0	a_1	a_2	a_3	σ
Water + ethanol systems	303.15	3.2346	−4.0773	2.8114	0.7828	0.0427
	308.15	2.6950	−3.3193	2.3120	0.9020	0.0375
	313.15	2.2657	−2.7690	1.7801	0.9705	0.0320
	318.15	1.9103	−2.2714	1.4249	0.8768	0.0284
	323.15	1.5931	−1.9058	1.1722	0.8063	0.0250
0.05% Aqueous SE + ethanol systems	303.15	3.2999	−4.0187	2.9143	0.7423	0.0435
	308.15	2.7282	−3.3246	2.3371	0.8584	0.0393
	313.15	2.2470	−2.7679	1.6358	0.6691	0.0318
	318.15	1.9194	−2.2670	1.4745	0.9201	0.0296
	323.15	1.5989	−1.8961	1.2256	0.7752	0.0276
0.1% Aqueous SE + ethanol systems	303.15	3.2955	−4.1739	2.8397	0.9485	0.0458
	308.15	2.7311	−3.3740	2.3864	1.0273	0.0419
	313.15	2.2592	−2.8180	1.8377	1.1241	0.0326
	318.15	1.9347	−2.3124	1.4562	0.9762	0.0323
	323.15	1.6094	−1.9328	1.1663	0.8482	0.0292

solution systems, respectively. From these figures, it is seen that there is no appreciable change in viscosity after adding SE to the systems. In SE systems, density increases slightly in comparison to corresponding systems without SE. This result can be explained by the fact that the concentration of SE was so less that the effect of SE on the experimental systems was negligible. It is expected that if the concentration of SE is high enough, then the density of the systems may be perturbed significantly and the effect may be observed.

Table 7. Coefficient, a_i, of Redlich–Kister equation (2) expressing η^E in cP and standard deviation, σ for the *n*-propanol systems.

Systems	T/K	a_0	a_1	a_2	a_3	σ
Water + *n*-propanol systems	303.15	3.7647	−4.2378	3.4864	−0.8833	0.0245
	308.15	3.1497	−3.6366	2.8036	−0.2221	0.0257
	313.15	2.6545	−3.0186	2.2527	−0.0251	0.0260
	318.15	2.2515	−2.5644	1.8057	0.1682	0.0259
	323.15	1.8850	−2.2007	1.5028	0.3571	0.0258
0.05% Aqueous SE + *n*-propanol systems	303.15	3.7164	−4.2086	3.2513	−0.9104	0.0235
	308.15	3.1370	−3.5759	2.8752	−0.4435	0.0178
	313.15	2.6336	−3.1215	2.2310	0.0825	0.0209
	318.15	2.1868	−2.6060	1.8567	0.4400	0.0230
	323.15	1.8540	−2.2935	1.5732	0.5817	0.0221
0.1% Aqueous SE + *n*-propanol systems	303.15	3.7703	−4.1476	3.5419	−0.9824	0.0191
	308.15	3.1733	−3.4246	2.7801	−0.6008	0.0219
	313.15	2.6077	−2.9472	2.1601	−0.1377	0.0234
	318.15	2.2342	−2.5630	1.7760	0.0723	0.0232
	323.15	1.8790	−2.1515	1.5098	0.2363	0.0234

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References

[1] M.H. Kabir, M.A. Motin, M.E. Huque, *Phys. Chem. Liq.*, **42**(3), 279 (2004).
[2] P.C. Dey, M.A. Motin, T.K. Biswas, E.M. Huque, *Monat. Chem.*, **134**, 797 (2003).
[3] S. Afroz, M.A. Motin, T.K. Biswas, E.M. Huque, *Phys. Chem. Liq.*, **41**, 249 (2003**)**.
[4] C. Tanford, *The Hydrophobic Effect – Formation of Micelles and Biological Membranes*, Wiley-Interscience, New York (1973).
[5] L. Morávková, J. Linek, *J. Chem. Thermodyn.*, **35**, 113 (2002).
[6] S. Aktar, M.M.H. Bhuiyan, M.S. Uddin, B. Sultana, M. Nessa, M.A. Saleh, Viscosity of aqueous solutions of some alcohols, In Press (1998).
[7] P.S. Nikam, M.C. Jadhav, M. Hasan, *J. Chem. Eng. Data*, **40**, 931 (1995).
[8] M.A. Saleh, S. Akhtar, M.S Ahmed, M.H. Uddin, *Phys. Chem. Liq.*, **40**, 621 (2002).