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EFFECT OF SODIUM DODECYL SULFATE ON VISCOMETRIC PROPERTIES OF METHANOL, ETHANOL, *n*-PROPANOL AND *iso*-PROPANOL AT DIFFERENT TEMPERATURES

M. A. MOTIN*, M. A. HAFIZ MIA, A. K. M NASIMUL ISLAM, K M SALIM REZA AND M. A. YOUSUF

Department of Chemistry, Khulna University of Engineering & Technology (KUET), Khulna 9203, Bangladesh

Abstract

The critical micelle concentration (CMC) of Sodium Dodecyl Sulfate (SDS) in water was determined from the conductance and viscosity measurement. The estimated value of CMC was found to be 0.0085 mol.L^{-1} at 29^{0}C. The concentration of SDS in pre-micellar and post-micellar region of 0.005M and 0.01M, respectively were used for the viscometric measurements of Methanol, Ethanol, *n*-Propanol, *iso*-Propanol at different temperatures. Viscosities of ternary mixtures of Methanol, Ethanol, *n*-Propanol and *iso*-Propanol in 0.005M and 0.01M aqueous SDS have been studied over the entire range of composition at 298.15- 323.15K with an interval of 5K except Methanol. Methanol system was studied at 298.15-308.15K owing to its low boiling point. Viscosities increase rapidly with alcohol concentration and show maxima in aqueous SDS rich region at 0.2 – 0.3 mole fraction of alcohols. The position of maxima virtually does not change remarkably with the variation of temperature. The excess viscosities, η^E values are found to be positive and large in magnitude, indicating that aqueous SDS solutions of alcohols are highly non ideal. The heights of the maxima are in the order:

iso-Propanol + aqueous SDS > *n*-Propanol + aqueous SDS > Ethanol + aqueous SDS > Methanol + aqueous SDS.

The excess viscosities, η^E data have been fitted by the least square method to the four parameter Redlich-Kister equation and the values of the parameter a_j have been reported.

Introduction

Solution of highly surface-active materials exhibit unusual physical properties. In dilute solution the surfactant acts as a normal solute. 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 etc. is observed Micelle formation of surfactant molecules in water solution is a typical hydrophobic process[1]. In water medium, surfactant molecules with their long hydrophobic tails undergo hydrophobic hydration.

Alcohols are self-associated liquids through H-bonding. Alcohols possess hydrophilic -OH group as well as hydrophobic group. Interactions between aqueous SDS and alcohols

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* Author for correspondence: e-mail: abdulmotin75@yahoo.com

are extremely complex. The mode of interaction of these two groups towards SDS is completely different. The hydrophilic -OH group of an alcohol forms H-bond with aqueous SDS through hydrophilic interactions and disrupts the aqueous SDS structure, while the alkyl group promotes the structure of aqueous SDS molecules surrounding this group through hydrophobic hydration. Recently, we reported the densities and excess molar volumes of alcohols in water Surf Excel solution[2] and the volumetric and viscometric properties of carbohydrates in water Surf Excel[3] and the electrolytes in water SDS[4] systems. Research on some binary alcohol systems thermophysical properties has been reported by several authors [5-12].

Here, we report the effect of some simple alcohols on the structure of water SDS systems based on viscometric measurements. Micelle-forming molecules in SDS may force water to be in a certain structural form in the water SDS system. The perturbations of this forced structure in water SDS 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. The data are also useful for the design of mixing, storage and process equipment.

Experimental

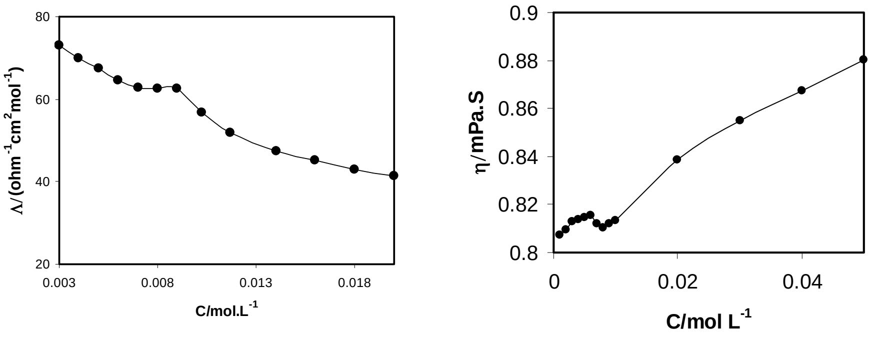
Materials. The chemicals used were purchased from Aldrich chemical co. with the quoted purities : Methanol (99.5%), Ethanol (99.0%), n-Propanol (99.0%), *iso*-Propanol (99.5%) and sodium dodecyl sulfate (SDS) (99.5%). These alcohols were used without any further purification, except that they were allowed to stand over molecular sieves (4A) about one week before measurements.

Density Measurements. Densities were measured by using 5 mL bicapillary pycnometers. The volumes of the pycnometers were calibrated with deionized and doubly distilled water at (298.15, 303.15, 308.15, 313.15, 318.15 and 323.15) K. The densities of solutions were determined from the mass of the solution in the pycnometer after reaching thermal equilibrium with a water bath at the studied temperatures. Temperatures were controlled by a thermostatic water bath fluctuating to ±0.05K. A HR-200 electronic balance with an accuracy of ± 0.0001g was used for the mass determination. Reproducibility of the results was checked by taking each measurement three times.

Viscosity Measurements. The viscosities were measured by calibrated U-type Ostwald viscometer of the British standard institution with sufficiently long efflux time to avoid kinetic energy correction. The provided calibration constants were checked with water, ethanol, and 1-hexane. The flow time of liquids was recorded by a timer to ±0.1sec. Temperatures were controlled by a thermostatic water bath fluctuating to ±0.05K. The viscosity, η of the solutions was calculated by $\eta = A\rho t$, where t is the flow time, ρ is the density of the solution, and A is the viscometer constant. The viscosity, η and the density, ρ were reproducible to within $\pm 3\times10^{-4}$ mPa.s and $\pm 2\times10^{-5}$ g.cm^{-3}, respectively.

Results and Discussion

The CMC of Sodium Dodecyl Sulfate (SDS) in water was determined from the conductance and viscosity measurement. The concentration dependence of molar conductivity of aqueous solutions of SDS data are shown in Figure 1(a). The molar conductivity decreases with increasing SDS concentration and then remains unchanged and finally decreases again. It shows a sharp break in its value where micelle starts to form and it is determined by extrapolating the molar conductivity data in the pre-micellar region to intersect with a straight line drawn through the data in the post-micellar region. Viscosities vs. concentration of aqueous solution of SDS are shown in Figure 1(b). The viscosities increases with increasing SDS concentration and then decreases and eventually increases again. The minima of viscosity express the CMC of SDS. The estimated value of CMC was found to be 0.0085 mol.L^{-1} at 29°C.



(a) (b)

Fig. 1. Plots of molar conductance (a) and viscosity (b) vs. concentration of SDS in aqueous solution at 302.15K.

The conductance data is in good agreement with the viscosity data. The literature value also has been found to be satisfactory with this data[13]. The effect of surfactant, SDS to alcohol systems has been studied in terms of viscometric properties measurement. The concentration of SDS in pre-micellar and post-micellar region of 0.005M and 0.01M respectively were used for these measurements.

The densities and viscosities of the pure components are shown in Table 1 together with the literature values for Methanol, Ethanol, *n*-Propanol and *iso*-Propanol, wherever possible for comparison. The agreement between the measured values and literature values has been found to be almost satisfactory. The viscosities of Methanol, Ethanol, *n*-Propanol and *iso*-Propanol in 0.005M and 0.01M aqueous SDS systems at 298.15, 303.15, 308.15, 313.15, 318.15 and 323.15K except Methanol over the entire composition range are shown in Tables 2-5 (for similar nature data of 0.005M SDS containing alcohol systems are not shown). Methanol system was studied at 298.15, 303.15 and 308.15K owing to its low boiling point.

Table 1. Comparison of experimental and literature values of density, ρ (g.cm^{-3}) and viscosity, η (mPa.s) of pure components at different temperatures.

Component	Temperature (K)	Density (g.cm^{-3})		Viscosity (mPa.s)	
		ρ_{lit}	ρ_{exp}	η_{lit}	η_{exp}
Methanol	298.15	0.78720[14]	0.78732	0.553[23]	0.552
	303.15	0.78242[15]	0.78276	0.510[24]	0.511
	308.15	0.77710[16]	0.77743	0.484[25]	0.490
	313.15	0.77250[17]	0.77254	0.454[25]	0.458
	318.15	0.76928 [18]	0.76670	0.426[25]	0.428
	323.15	0.76280[17]	0.75860	0.400[23]	0.405
Ethanol	298.15	0.80190[19]	0.80887	1.090[23]	1.135
	303.15	0.79825[18]	0.80451	1.181[25]	1.206
	308.15	0.79452[18]	0.79903	1.064[25]	1.087
	313.15	0.78016[18]	0.79320	0.965[25]	0.965
	318.15	0.78576[18]	0.78830	0.871[25]	0.871
	323.15	0.77134[18]	0.78356	0.801[25]	0.795
n-Propanol	298.15	0.79969[20]	0.80050	1.934[26]	1.923
	303.15	0.79584[15]	0.79632	1.663[15]	1.695
	308.15	0.79750[18]	0.79191	1.542[25]	1.523
	313.15	0.78750[17]	0.78789	1.300[23]	1.343
	318.15	0.78918[18]	0.78241	1.244[25]	1.206
	323.15	0.77850[17]	0.77922	1.109[25]	1.069
iso-Propanol	298.15	0.78000[21]	0.77831	2.036[27]	2.026
	303.15	0.77710[19]	0.77447	-	1.764
	308.15	0.77246[22]	0.77119	1.542[22]	1.522
	313.15	-	0.76697	-	1.318
	318.15	-	0.76258	-	1.152
	323.15	-	0.75813	-	1.007

The comparison of variation of viscosities at 298.15K as a function of the mole fraction of all the alcohols is shown in Figure 2. The following characteristic features of viscosity (Tables 2-5) are observed:

a) Viscosities increase rapidly with alcohol concentration and show maxima in the aqueous SDS rich region at 0.2 – 0.3 mole fraction of alcohol. The position of maxima virtually does not change remarkably with the variation of temperature.

b) Viscosity decreases with rise of temperature.

c) The viscosity maxima follow the order:

   iso-Propanol + aqueous SDS > *n*-Propanol + aqueous SDS > Ethanol + aqueous SDS > Methanol + aqueous SDS

d) At the alcohol rich region shallow minima are observed for *iso*-Propanol at ~ 0.7-0.8 mole fraction of alcohol. The minima seem to disappear with the rise of temperature.

In SDS systems, viscosity increases in comparison to corresponding systems without SDS. This indicate that the aqueous SDS solution are reorganized the alcohol structure again so that the viscosity increasing are observed. The viscosity of alcohols in water and SDS systems has been found to be in the order of,

Alcohol - 0.01M SDS > Alcohol - 0.005M SDS > Alcohol - Water

Excess viscosities, η^E were calculated by using equation 1

$$\eta^E = \eta_{\mathrm{exp}t.} - \eta_{id} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

where, η_{expt} is the observed viscosity and η_{id} is the ideal viscosity.

The η^E values are shown in Tables 2-5. The excess viscosities, η^E were fitted by least squares method to a polynomial equation 3.

$$\eta^E = X_1X_2 \sum_{i=0}^{n} a_\mathrm{i}(1\text{-}2X_1)^\mathrm{i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(2)$$

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.

The values of the fitting parameters along with the standard deviation of Ethanol systems are presented in Table 6 as sample. The comparison of variation of η^E against mole fraction of alcohol (x_2) at 298.15K is shown in Figure 3. The η^E values are found to be positive and large in magnitude, indicating that the aqueous SDS solutions of alcohols are highly non ideal. All the curves pass through maxima in aqueous SDS –rich region. The height of the maxima are in the order:

iso-Propanol + aqueous SDS > *n*-Propanol + aqueous SDS > Ethanol + aqueous SDS > Methanol + aqueous SDS

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

a) Strong Alcohol- aqueous SDS and Alcohol-Alcohol interactions,

b) Hydrophobic hydration of Alcohols.

The rapidly ascending part of viscosity curves (Figure 2) in the dilute region of alcohols can be explained primarily in terms of the phenomenon called hydrophobic hydration, which assumes that, in aqueous SDS rich region, the aqueous SDS molecules form highly ordered structures through hydrogen bonding around the hydrocarbon moieties of alcohols. 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 aqueous SDS, cages are formed continuously till the aqueous SDS molecules necessary to form these cages are available. Simultaneously, the hydroxyl groups of alcohol form hydrogen bonds with the surrounding aqueous SDS molecules. The increase in viscosity with the mole fraction of alcohol in aqueous SDS rich region may be attributed to these two effects collectively. This evidence suggest that, at least in the case of t-Butanol and *iso*-propanol , the hydroxyl group is involved in H-bonding with aqueous solution[28].

After attaining the state of maximum viscosity further addition of alcohol continuously breaks down both cages of alcohol-water and alcohol- aqueous SDS associates, and instead, 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. The hydrophobic effect obviously increases with the size of the hydrocarbon chain of alcohols, while the hydrophilic effect is expected to be the same for all the studied alcohols.

The difference in maxima of viscosity over the temperature range ($\Delta\eta_{\max}$) of the different systems can be explained in terms of the thermal fragility of the cages formed. In comparison with alcohol- aqueous SDS association, the aqueous SDS - aqueous SDS association in the cage structure is assumed to be more fragile to heat. Examination of viscosity curves of different alcohol solutions (Tables 2-5) show that $\Delta\eta_{\max}$ varies in the order,

iso-Propanol (1.8 mPa.s) > *n*-Propanol (1.3 mPa.S) > Ethanol (1.1 mPa.S) > Methanol (0.75 mPa.S)

The values, therefore, indicate the extent of the destruction of the cages structures by thermal effect which, in turn, reflects the extent of cage formation. The cages formed by the water - water association around hydrocarbon tails of alcohols are also assumed to be thermally unstable than water - water association in normal water[29,30].

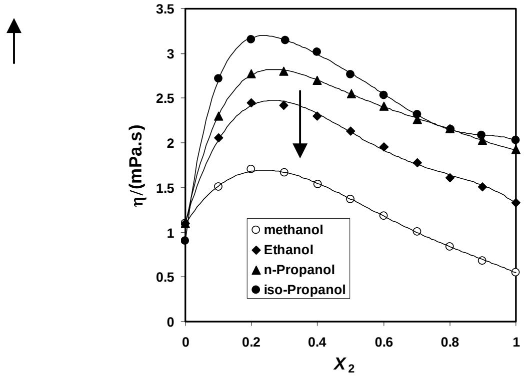


Fig. 2. Plots of viscosity vs mole fraction of Methanol, Ethanol, *n*-Propanol and *iso*-Propanol in 0.01M aqueous SDS system at 298.15K.

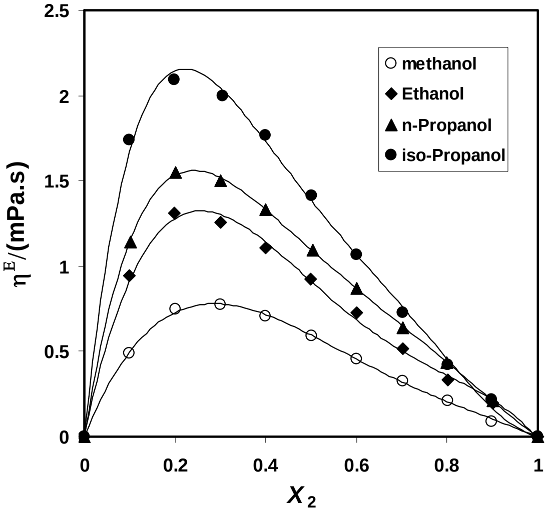


Fig. 3. Plots of excess viscosity vs mole fraction of Methanol, Ethanol, *n*-Propanol and *iso*-Propanol in 0.01M aqueous SDS system at 298.15K.

The shallow minima occurring at 0.7-0.8 mole fraction of alcohol as showed in the *iso*-Propanol (Figure 2 and Table 5) seen to be somewhat prominent at lower temperatures. This observation is in agreement with that made by Tanaka et al[31]. In the study of the viscosity of aqueous solutions of isomeric butanols, Scnanayake et al[32] noticed similar minima. A work by Kipkemboi et al[33] on the viscosity aqueous mixtures of t-Butanol in the temperature range 288-318K also confirmed this phenomenon. Incidentally, minima of static dielectric constants of alcohol-water mixtures occur at about the same composition where the shallow minima of viscosity are observed[34,35]. Franks and Ives[35] explained these minima in terms of the formation of so called "centrosymmetric" associates which are thought to be composed of one water and four alcohol molecules. At the alcohol rich region shallow minima are observed prominently for *iso*-Propanol at 0.7-0.8 mole fraction in water and 0.005M SDS solutions. But the minima at the post micellar concentration (0.01M SDS) for *iso*-Propanol in SDS solutions are not so noticeable. This is may be due to the centrosymmetric association (one water and four alcohol molecules) are not available on addition of higher concentration of SDS.

In the present investigation at 298.15K, the maximum values of η^E have been found to be 0.7 (at $x_2 = 0.30$), 1.25 (at $x_2 = 0.5$), 1.55 (at $x_2 = 0.25$), 2.2 (at $x_2 = 0.25$) for the, 0.01M SDS -Water + Methanol, 0.01M SDS -Water + Ethanol, 0.01M SDS -Water + *n*-Propanol and 0.01M SDS-Water + *iso*-Propanol mixtures, respectively.

Table 6. Coefficient, a_i, of Redlich-Kister Equation express in η^E and standard deviation, σ for the Ethanol ,+0.005M SDS, + 0.01M SDS systems.

Systems	T/ K	a_o	a_1	a_2	a_3	σ
0.005M SDS+Ethanol systems	298.15	4.009	-4.302	3.595	-1.437	0.022
	303.15	3.200	-3.303	2.851	-1.448	0.006
	308.15	2.685	-2.805	2.094	-0.565	0.009
	313.15	2.265	-2.296	1.634	-0.245	0.007
	318.15	1.900	-1.858	1.262	-0.278	0.006
	323.15	1.576	-1.612	0.998	-0.097	0.004
0.01M SDS+Ethanol systems	298.15	3.641	-4.172	4.102	-1.881	0.021
	303.15	2.894	-3.228	3.100	-1.743	0.012
	308.15	2.416	-2.615	2.354	-1.219	0.008
	313.15	1.998	-2.006	1.906	-1.039	0.013
	318.15	1.644	-1.611	1.448	-0.817	0.009
	323.15	1.369	-1.344	1.171	-0.610	0.008

The interaction parameters (ε) have been calculated by using the equation 3

$$\varepsilon = \frac{\ln \eta_{\exp t} - \ln \eta_{id}}{X_1 X_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where, ε = Interaction parameter, $\eta_{\exp t.}$ = observed viscosity, η_{id} = calculated viscosity, and x_1 and x_2 are there mole fractions respectively.

The values of interaction parameters for different systems are shown in Tables 2-5. The values have been found to be positive and quite large in magnitude in aqueous SDS -rich region for all the systems. The ε values are decrease with the increase of temperature.

From the studies of ε and η^E values of a number of binary mixtures of different polar or non-polar liquids, Fort and Moore[36] indicated an approximate idea about the strength of interaction between liquids. They are:

a. If $\varepsilon > 0$ and $\eta^E > 0$ and both are large in magnitudes, then strong specific interaction between the components would be anticipated.
b. If $\varepsilon < 0$ and $\eta^E > 0$ and both are not that much large in magnitudes, then weak interaction would be present between the components.
c. If $\varepsilon < 0$ and $\eta^E < 0$ and the magnitude of both parameters are large, then specific interaction would be absent and dispersion force would be dominant.

In our studied systems, both ε and η^E values are positive and large in magnitude. Therefore, the positive interaction parameters indicate that strong interactions between the components of the mixtures[36] are occurred. The interaction parameters, ε increase rapidly with alcohol concentration, showing maxima at ~ 0.2-0.3 mole fraction of alcohol and then decrease continuously and finally increases slightly. The position of maxima virtually does not change remarkably with the variation of temperature. In the present investigation at 298.15K, the maximum values of ε have been found to be 4.8 (at $x_2 = 0.1$), 6.5 (at $x_2 = 0.1$), 6.9 (at $x_2 = 0.1$), 7.9 (at $x_2 = 0.1$) for the aqueous SDS + Methanol, aqueous SDS + Ethanol, aqueous SDS + *n*-Propanol and aqueous SDS + *iso*-Propanol mixtures, respectively. The height of the maxima is in the order has been found:

iso-Propanol + aqueous SDS > *n*-Propanol + aqueous SDS > Ethanol + aqueous SDS > Methanol + aqueous SDS.

The ascending part of interaction parameters in aqueous SDS region, the aqueous SDS molecules form highly ordered structure that renders the high positive value of interaction parameters.

Conclusion

The studies on the solution properties of ternary mixtures of Methanol + 0.005M SDS and 0.01M aqueous SDS, Ethanol + 0.005M SDS and 0.01M aqueous SDS, *n*-Propanol + 0.005M SDS and 0.01M aqueous SDS and *iso*-Propanol + 0.005M SDS and 0.01M aqueous SDS solutions, show strong solute–solvent interactions in aqueous-SDS region, the aqueous SDS molecules form highly ordered structures through hydrogen bonding around the hydrocarbon moieties of alcohols. The viscosities increase with alcohol concentration and show maxima in the aqueous-SDS rich region. The position of maxima does not change with the variation of temperature. The shallow minima occurring at ~ 0.7-0.8 mole fraction of *iso*-Propanol, seen to be somewhat prominent at lower temperatures. This is due to the formation of “centrosymmetric” association. The excess viscosities values are found to be positive and large in magnitude, indicating that the aqueous solutions of alcohols are highly non ideal. The viscometric data are consistent with the volumetric properties data. The interaction parameters were found to be positive in magnitude indicating strong solute-solvent interaction. Although the value of viscosity of the studied systems in pre-micellar and post-micellar aqueous SDS solutions (0.005M SDS and 0.01M SDS) are higher than the pure water solutions, but the nature of curves are almost similar as to SDS systems.

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C(mol. L^{-1})

C(mol. L^{-1})

Table 2. Viscosity (η), Excess viscosity (η^E) and Interaction parameter (ε) of Methanol + 0.01M SDS system at 298.15K, 303.15K and 308.15K

X_2	298.15K			303.15K			308.15K		
	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε
0.0000	1.095	0.000	0.000	0.969	0.000	0.000	0.882	0.000	0.000
0.1002	1.511	0.489	4.335	1.306	0.397	4.024	1.162	0.331	3.712
0.2000	1.702	0.747	3.613	1.447	0.595	3.309	1.281	0.497	3.068
0.3001	1.664	0.772	2.970	1.431	0.631	2.772	1.271	0.531	2.579
0.4006	1.540	0.707	2.561	1.336	0.587	2.408	1.197	0.500	2.251
0.5012	1.367	0.590	2.259	1.182	0.479	2.079	1.075	0.418	1.969
0.6006	1.184	0.458	2.039	1.044	0.384	1.914	0.948	0.328	1.771
0.7012	1.005	0.327	1.881	0.905	0.287	1.817	0.825	0.241	1.647
0.8004	0.842	0.209	1.784	0.765	0.185	1.729	0.705	0.154	1.541
0.8991	0.683	0.091	1.579	0.629	0.084	1.582	0.587	0.067	1.343
1.0000	0.552	0.000	0.000	0.511	0.000	0.000	0.490	0.000	0.000

C(mol. L^{-1}) C(mol. L^{-1}

Table 3. Viscosity (η), Excess viscosity (η^E) and Interaction parameter (ε) of Ethanol + 0.01M SDS system at 298.15K, 303.15K, 308.15K, 313.15K, 318.15K and 323.15K

	298.15K			303.15K			308.15K			313.15K			318.15K			323.15K		
X_2	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε
0.0000	1.095	0.000	0.000	0.969	0.000	0.000	0.882	0.000	0.000	0.797	0.000	0.000	0.726	0.000	0.000	0.663	0.000	0.000
0.1005	2.058	0.941	6.759	1.737	0.746	6.214	1.506	0.605	5.684	1.305	0.492	5.238	1.131	0.392	4.703	0.994	0.319	4.277
0.1997	2.453	1.313	4.797	2.038	1.026	4.381	1.731	0.811	3.956	1.474	0.645	3.605	1.273	0.520	3.288	1.120	0.433	3.056
0.2992	2.420	1.258	3.499	2.035	1.001	3.228	1.762	0.823	3.002	1.522	0.677	2.809	1.315	0.548	2.572	1.154	0.454	2.386
0.3989	2.295	1.109	2.755	1.931	0.874	2.512	1.684	0.725	2.349	1.445	0.585	2.162	1.265	0.484	2.012	1.110	0.397	1.848
0.4988	2.132	0.922	2.268	1.811	0.730	2.065	1.591	0.613	1.944	1.383	0.506	1.821	1.203	0.408	1.656	1.069	0.343	1.550
0.6005	1.958	0.724	1.925	1.684	0.579	1.756	1.480	0.480	1.635	1.306	0.412	1.579	1.149	0.340	1.460	1.023	0.284	1.354
0.7019	1.776	0.517	1.645	1.536	0.406	1.468	1.363	0.342	1.380	1.200	0.288	1.311	1.069	0.244	1.240	0.953	0.200	1.126
0.8017	1.614	0.330	1.440	1.416	0.261	1.281	1.261	0.218	1.196	1.123	0.193	1.188	0.992	0.1518	1.045	0.894	0.127	0.967
0.9002	1.505	0.196	1.551	1.315	0.135	1.209	1.183	0.119	1.176	1.054	0.107	1.191	0.942	0.086	1.073	0.854	0.073	0.999
1.0000	1.335	0.000	0.000	1.206	0.000	0.000	1.087	0.000	0.000	0.965	0.000	0.000	0.871	0.000	0.000	0.795	0.000	0.000

Table 4. Viscosity (η), Excess viscosity (η^E) and Interaction parameter (ε) of n-Propanol + 0.01M SDS system at 298.15K, 303.15K, 308.15K, 313.15K, 318.15K and 323.15K

	298.15K			303.15K			308.15K			313.15K			318.15K			323.15K		
X_2	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε
0.0000	1.095	0.000	0.000	0.969	0.000	0.000	0.882	0.000	0.000	0.797	0.000	0.000	0.726	0.000	0.000	0.663	0.000	0.000
0.1006	2.303	1.144	7.588	1.931	0.906	7.001	1.671	0.739	6.453	1.451	0.610	6.020	1.264	0.500	5.563	1.122	0.425	5.260
0.2005	2.775	1.549	5.096	2.310	1.226	4.721	1.996	1.012	4.410	1.743	0.854	4.201	1.507	0.702	3.915	1.326	0.593	3.701
0.2991	2.800	1.504	3.675	2.339	1.194	3.406	2.031	0.992	3.199	1.757	0.8120	2.998	1.528	0.682	2.819	1.337	0.568	2.637
0.3990	2.702	1.331	2.830	2.266	1.055	2.613	1.974	0.877	2.450	1.700	0.711	2.259	1.489	0.598	2.142	1.303	0.494	1.989
0.5026	2.550	1.097	2.249	2.163	0.879	2.088	1.872	0.711	1.911	1.637	0.591	1.790	1.435	0.496	1.696	1.267	0.416	1.593
0.6011	2.408	0.872	1.874	2.044	0.688	1.712	1.798	0.573	1.601	1.585	0.482	1.511	1.389	0.401	1.422	1.224	0.330	1.311
0.7022	2.263	0.637	1.5799	1.952	0.517	1.471	1.723	0.428	1.367	1.518	0.352	1.263	1.344	0.304	1.225	1.190	0.250	1.128
0.7993	2.155	0.437	1.414	1.866	0.351	1.298	1.656	0.291	1.204	1.463	0.235	1.091	1.297	0.203	1.064	1.149	0.162	0.949
0.8998	2.031	0.213	1.230	1.780	0.177	1.163	1.582	0.140	1.025	1.415	0.118	0.969	1.250	0.099	0.912	1.124	0.087	0.894
1.0000	1.923	0.000	0.000	1.695	0.000	0.000	1.523	0.000	0.000	1.369	0.000	0.000	1.212	0.000	0.000	1.090	0.000	0.000

Table 5. Viscosity (η), Excess viscosity (η^E) and Interaction parameter (ε) of *iso*-Propanol + 0.01M SDS system at 298.15K, 303.15K, 308.15K, 313.15K, 318.15K and 323.15K

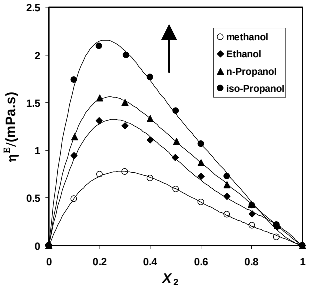
	298.15K			303.15K			308.15K			313.15K			318.15K			323.15K		
X_2	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε	$\frac{\eta}{mPa.s}$	$\frac{\eta^E}{mPa.s}$	ε
0.0000	0.904	0.000	0.000	0.796	0.000	0.000	0.725	0.000	0.000	0.658	0.000	0.000	0.601	0.000	0.000	0.550	0.000	0.000
0.1004	2.718	1.738	11.288	2.188	1.325	10.308	1.867	1.085	9.645	1.576	0.870	8.892	1.354	0.713	8.267	1.177	0.592	7.744
0.1988	3.155	2.093	6.838	2.559	1.626	6.337	2.174	1.333	5.966	1.855	1.100	5.639	1.582	0.897	5.260	1.386	0.765	5.045
0.3042	3.150	1.994	4.737	2.614	1.600	4.474	2.232	1.324	4.246	1.905	1.092	4.022	1.612	0.879	3.724	1.401	0.740	3.548
0.3990	3.017	1.770	3.683	2.477	1.383	3.41	2.124	1.149	3.248	1.806	0.938	3.054	1.555	0.776	2.882	1.345	0.644	2.720
0.5003	2.768	1.414	2.861	2.280	1.095	2.617	1.961	0.910	2.495	1.670	0.739	2.335	1.449	0.617	2.217	1.252	0.508	2.079
0.6000	2.534	1.067	2.277	2.114	0.831	2.080	1.833	0.702	2.010	1.563	0.565	1.867	1.355	0.467	1.760	1.174	0.383	1.645
0.7031	2.322	0.727	1.800	1.962	0.569	1.641	1.703	0.482	1.594	1.464	0.392	1.492	1.271	0.321	1.397	1.109	0.267	1.319
0.8026	2.150	0.422	1.381	1.842	0.334	1.264	1.605	0.290	1.258	1.397	0.248	1.232	1.218	0.205	1.165	1.070	0.176	1.133
0.8975	2.082	0.217	1.197	1.778	0.152	0.972	1.551	0.140	1.028	1.338	0.111	0.938	1.167	0.089	0.867	1.021	0.074	0.815
1.0000	2.026	0.000	0.000	1.764	0.000	0.000	1.522	0.000	0.000	1.318	0.000	0.000	1.152	0.000	0.000	1.007	0.000	0.000

Graphical Abstract

EFFECT OF SODIUM DODECYL SULFATE ON VISCOMETRIC PROPERTIES OF METHANOL, ETHANOL, *n*-PROPANOL AND *iso*-PROPANOL AT DIFFERENT TEMPERATURES

M. A. MOTIN*, M. A. HAFIZ MIA, A. K. M NASIMUL ISLAM, K M SALIM REZA AND M. A. YOUSUF

Viscosities and excess viscosities of ternary mixtures of Methanol, Ethanol, *n*-Propanol and *iso*-Propanol in 0.005M and 0.01M aqueous SDS have been studied over the entire range of composition at 298.15-323.15K.



Plots of excess viscosity vs mole fraction of Methanol, Ethanol, *n*-Propanol and *iso*-Propanol in 0.01M aqueous SDS system at 298.15K.