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Density and Viscosity Measurements of Binary Alkanol Mixtures from (293.15 to 333.15) K at Atmospheric Pressure

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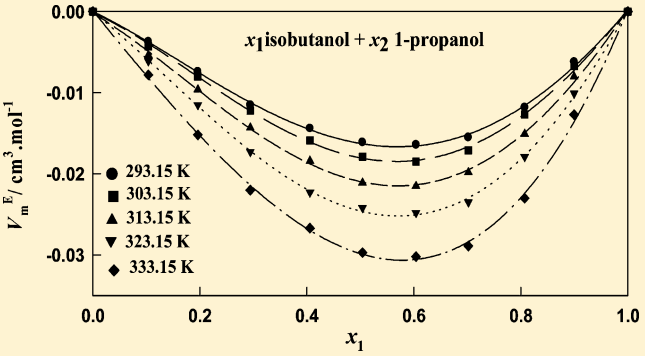
ABSTRACT: Density and viscosity of binary mixtures of {$x_1$isobutanol + $x_2$1-propanol}, {$x_1$isobutanol + $x_2$2-propanol}, and {$x_1$3-amino-1-propanol + $x_2$1-propanol} were measured over the entire composition range and from temperatures (293.15 to 333.15) K at ambient pressure. The excess molar volumes and viscosity deviations were calculated and correlated by the Redlich−Kister and McAllister equations, respectively. The excess molar volumes are negative over the entire mole fraction range for all of the mixtures and become more negative with increasing temperature. The viscosity deviations of the binary mixtures are negative in the entire composition range and decrease with increasing temperature.



INTRODUCTION

Alkanols are important compounds in both industry and science. Because the physiochemical properties of alkanols are mainly affected by hydroxyl group,[1] then these properties can be used as input data for evaluating theoretical models related to study the hydrophobic interactions.[2,3] Alkanols can also be used in the synthesis of many other organic compounds. Some industrial applications of alkanols consist of perfumes, cosmetics, paint, varnish, drugs, fuel, explosives, fats, waxes, resin, plastics, rubber, and detergents.[4]

Amines, alkanols, and their binary mixtures have found applications as solvent in chemistry and technology.[5] The nature of interactions between amines and alcohols are hydrogen bonding. Hydrogen bonding systems have important roles in chemical, physical, and biological processes and drug synthesis.[1,6] Aminoalcohols are an important class of organic compounds which are used as chiral auxiliaries and ligands.[7−9] One member of these materials is 3-amino-1-propanol which is used as an ice crystallization inhibitor[10] and for removing acidic components carbon dioxide or hydrogen sulfide from gas streams of industrial origin or from polluted atmosphere.[11−13]

Mixtures containing oxygenated compounds such as alkanols are also important materials in the oil industry because of their application in enhancing octane number in gasoline as additives and pollution reducing properties. Binary mixtures of alkanols are interesting due to their self-association between like molecules and capability of forming intermolecular hydrogen bonds created between unlike molecules upon mixing. So, the treatment of this class of mixtures could be helpful in examination of theoretical models.

In this work, the excess molar volume, V_m^E, and viscosity deviation, $\Delta\eta$, of some binary alkanol mixtures were presented. We have measured densities and viscosities of the binary mixtures {isobutanol + 1-propanol}, {isobutanol + 2-propanol}, and {3-amino-1-propanol + 1-propanol} along with their pure components in the temperature range of (293.15 to 333.15) K. The data were measured over the entire composition range at ambient pressure. For the studied systems, we found no data in the literature. The obtained excess molar volumes and viscosity deviations were correlated by Redlich−Kister[14] and McAllister[15] equations, respectively. They were also discussed via hydrogen bond interactions between component molecules and packing effects, which origins from the structural factors.

EXPERIMENTAL SECTION

Chemicals. Isobutanol and 3-amino-1-propanol were supplied by Merck Company with purities higher than 99 %, while 1-propanol was prepared by the same Company with purity higher than 99.8 %. 2-Propanol was purchesed by BDH with purity higher than 99.5 %. All the purities are in mass fraction. The materials were degassed just before experiment and have been used without further purification. The densities and viscosities of pure components along with the literature data[16−31] are listed in Table 1.

Density Measurements. An Anton-Paar DMA 4500 model vibrating tube densimeter, was used for measuring the densities of pure compounds and binary mixtures. The accuracy in the determining density was estimated to be $\pm 5{\cdot}10^{-5}$ g·cm^{-3}. The temperature in the cell was regulated to ± 0.01 K with solid state thermostat. The apparatus was calibrated once a day with dry air and double- distilled freshly degassed water.[32] Air tight stopper bottles were used for the preparation of the mixtures. The mass of dry bottle was first determined. The less volatile component of the mixture was introduced in the bottle, and the total mass was recorded.

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Table 1. Purities, Experimental Densities, and Viscosities along with Literature Data for Pure Compounds at Given Temperatures and Pressure of 0.1 MPa[a]

		ρ/g·cm^{-3}		η/mPa.·s	
purities in mass fraction	T/K	this work	lit.	this work	lit.
		Isobutanol			
99 %	293.15	0.80182	0.8018[b]	4.087	4.033[c]
	303.15	0.79406	0.79406[d]	2.877	2.876[e]
	313.15	0.78612	0.78612[d]	2.091	2.080[d]
	323.15	0.77794	0.77793[d]	1.576	1.602[d]
	333.15	0.76946	0.76944[d]	1.125	1.116[d]
		3-Amino-1-propanol			
99 %	293.15	0.98765	0.98650[f]	40.456	
	303.15	0.97965	0.9833[g]	23.981	24.1204[g]
	313.15	0.97161	0.975191[h]	15.312	
	323.15	0.96352	0.966881[h]	10.221	
	333.15	0.95538		6.962	
		1-Propanol			
99.8 %	293.15	0.80357	0.80359[I]	2.204	2.204[q]
	303.15	0.79553	0.79553[I]	1.513	1.6145[k]
	313.15	0.78735	0.78738[I]	1.018	1.1883[k]
	323.15	0.77898	0.77892[I]	0.790	0.8796[k]
	333.15	0.77038	0.77042[l]	0.470	0.5985[k]
		2-Propanol			
99.5 %	293.15	0.78535	0.78535[j]	2.362	2.362[p]
	303.15	0.77686	0.77680[j]	1.762	1.763[n]
	313.15	0.76807	0.76800[j]	1.200	
	323.15	0.75889	0.75890[m]	0.938	
	333.15	0.74925	0.74920[o]	0.604	0.624[o]

[a]Standard uncertainties u are $u(T)$ = ± 0.01 K, $u(\rho)$ = ± 5·10^{-5} g·cm^{-3}, and $u(\eta)$ = ± 5·10^{-2} mPa·s. [b]Reference 3. [c]Reference 4. [d]Reference 5. [e]Reference 6. [f]Reference 7. [g]Reference 8. [h]Reference 9. [I]Reference 10. [j]Reference 11. [k]Reference 12. [l]Reference 13. [m]Reference 14. [n]Reference 15. [o]Reference 16. [p]Reference 17. [q]Reference 18.

Subsequently, the other component was added, and the mass of bottle including two components was determined. Each mixture was immediately used, after it was mixed by shaking. All the weightings were performed on an electronic digital balance (AB 204-N Mettler) accurate to ± 1·10^{-5} g. The possible error in the mole fraction is estimated to be lower than ± 1·10^{-4}. Conversion to molar quantities was based on the relative atomic mass table of 2006 issued by IUPAC.[33] The uncertainty in the excess molar volumes estimated to be ± 1·10^{-4} cm^3. mol^{-1}.

Viscosity Measurements. Viscosity was determined using an Ubbelohde viscometer which was fixed in a water bath and the temperature was controlled with a precision of ± 0.01 K. The flow times were taken by using a digital chronometer model of KENKO KK-5898 with a precision of ± 0.01 s.

Measurements of density and viscosity were repeated at least three times to get the best averaged values.

RESULTS AND DISCUSSION

Excess Molar Volume of Mixtures. The excess molar volume of mixtures, V^E_m, can be calculated via the following equation:

$$V^E_m = V - \sum_{i=1}^{2} (x_i V_i^0) \quad (1)$$

where x_i and V_i^0 are the mole fraction and molar volume of the pure component i at any temperature and V is the molar volume of the mixture. The excess molar volumes can be correlated via a polynomial presented by Redlich−Kister[14] as

$$V^E_m = x_1 x_2 \sum_{i=1}^{k} A_i (1 - 2x_1)^i \quad (2)$$

where x_1 and x_2 are the mole fractions of the components and k is the order of polynomial equation (k = 4). A_i are the fitting parameters that can be correlated in terms of temperature as

$$A_i = \sum_{j=0}^{2} B_{ij} T^i \quad (3)$$

The B_{ij} coefficients are mixture dependent parameters and T is absolute temperature. These coefficients were calculated for V^E_m of binary mixtures and the results of such calculations are listed in Table 2. The standard deviations reported in this table were computed by using the following equation:

$$\sigma = \left(\sum_{i=1}^{n} \frac{(V^E_{exp,i} - V^E_{cal,i})^2}{(n-p)} \right)^{1/2} \quad (4)$$

where n is the number of experimental points and p is the number of adjustable parameters, A_i, in eq 2. Figure 1a−c shows the negative excess molar volumes over the entire mole fraction range for the binary mixtures under study that become more negative with increasing temperature from (293.15 to 333.15) K. These results are in consistency with our previous results of {3-amino-1-propanol + isobutanol} and {3-amino-1-propanol + 2-propane} mixtures.[34] In all of

Table 2. Coefficients of Rerlich−Kister Equation, B_{ij}, and Standard Deviations in Excess Molar Volumes, $\sigma(V^E_m)$, for Mixtures in the Temperature Range of (293.15 to 333.15) K

	i					
j	0	1	2	3	4	$\sigma(V^E_m)$/cm^3·mol^{-1}
0	−1.5312	−0.6434	−7.5174	3.6048	9.7855	
1	0.0106	0.0040	0.0488	−0.0233	−0.0633	0.0002
2	1.9013·10^{-5}	−5.7341·10^{-6}	−7.9056·10^{-5}	3.7468·10^{-5}	1.0238·10^{-4}	
0	−1.5193	−2.0526	−2.0591	2.5554	2.7000	
1	0.0103	0.0127	0.0137	−0.0155	−0.0183	0.0003
2	−1.8196·10^{-5}	−1.9892·10^{-5}	−2.2252·10^{-5}	2.3914·10^{-5}	3.0675·10^{-5}	
0	−9.0161	−2.3656	−12.9735	4.8957	17.8023	
1	0.0476	0.0156	0.0877	−0.0331	−0.1170	0.0039
2	−8.6192·10^{-5}	−2.5906·10^{-5}	−1.5463·10^{-4}	5.6650·10^{-5}	1.9683·10^{-4}	

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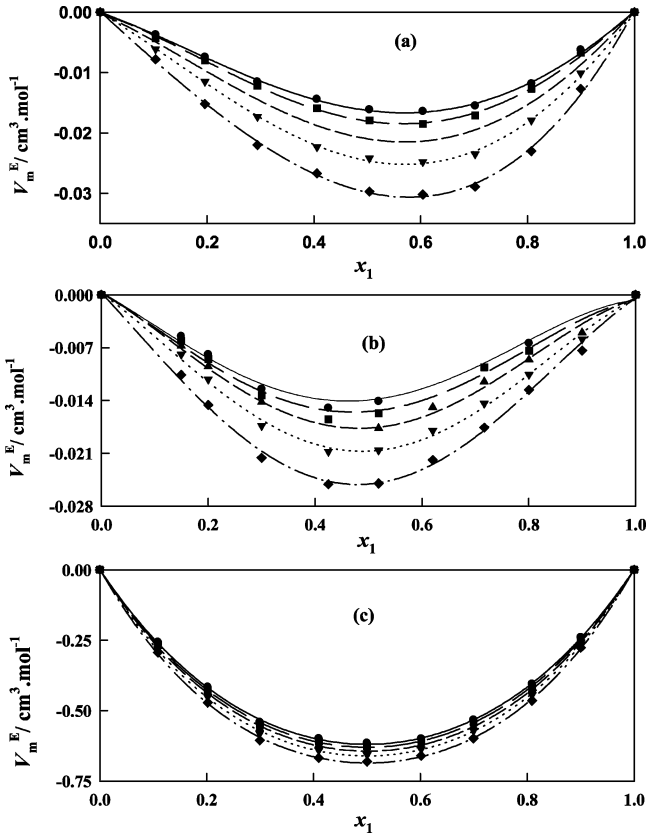

Figure 1. Excess molar volume, V_m^E, versus mole fraction, x_1, for (a) {$x_1$isobutanol + $x_2$1-propanol}, (b) {$x_1$isobutanol + $x_2$2-propanol}, and (c) {$x_1$3-amino-1-propanol + $x_2$1-propanol} at ●,——, 293.15 K; ■,— —, 303.15 K; ▲,– – –, 313.15 K; ▼,···, 323.15 K; ♦,—•—, 333.15 K. Solid lines and symbols indicate the calculated and experimental values, respectively.

the present and previous binary mixtures the excess molar volumes are negative, which means that the interactions between unlike molecules are stronger than those for like molecules. Also, the magnitudes of negative values in excess molar volumes in the mixtures containing 3-amino-1-propanol are greater than other mixtures. In the mixture containing 3-amino-1-propanol with two functional groups of OH and NH_2, the H-bond formation is more probable and so the interactions are stronger than the other mixtures without such an effectively associating fluid.

Viscosity of Binary Mixtures. The equation developed by McAllister[15] has been used successfully to correlate viscosity data of binary mixtures. The equation contains two adjustable interaction parameters ν_{12} and ν_{21}. The importance of this model is that it may be considered as some kind of bridge between the transport and the thermodynamic properties. This model is widely recommended to provide theoretical values for viscosity close to the experimental data. The model is based on Eyring's theory of absolute reaction rates[35] to present the kinematic viscosity of a binary mixture as

$$\ln \nu = x_1^3 \ln \nu_1 + x_2^3 \ln \nu_2 + 3x_1^2 x_2 \ln \nu_{12} + 3x_1 x_2^2 \ln \nu_{21} - \ln\left(x_1 + x_2\frac{M_2}{M_1}\right) + 3x_1^2 x_2 \ln\left(\frac{2 + M_2/M_1}{3}\right) + 3x_1 x_2^2 \ln\left(\frac{1 + 2M_2/M_1}{3}\right) + x_2^3 \ln\frac{M_2}{M_1} \quad (5)$$

The ν_{12} and ν_{21} are interaction parameters were obtained by data regression, and M_i and ν_i are molecular mass and kinematic viscosity of the pure component i, respectively. The relation between the kinematic and dynamic viscosities is $\nu = \eta/\rho$. These calculations for the binary mixtures under study were carried out using eq 5 and the experimental viscosities and densities of a binary mixture over entire composition range at any given temperature to find the η_{12} (= $\rho_{mix}\nu_{12}$) and η_{21} (= $\rho_{mix}\nu_{21}$) parameters and the results are listed in Table 3. The standard deviations reported in this table were computed by using the following equation:

$$\sigma(\%) = \left(\frac{1}{n-k}\sum_{i=1}^{n}\sum\left\{\frac{100(\eta_{exp,i} - \eta_{cal,i})}{\eta_{exp,i}}\right\}^2\right)^{1/2} \quad (6)$$

As Table 3 shows, the obtained viscosity interaction parameters, η_{12} and η_{21}, for all of the mixtures under study are positive values greater than unit. Then, the terms involving them in eq 5 can increase viscosities of the mixtures. This table also shows that the interaction parameters decrease with increasing temperature, which is a reasonable result. It is well-known that viscosity of liquids decreases with increasing temperature. These parameters also are greater in magnitude in the case of {3-amino-1-propanol + 1-propane} mixture, which is a mixture with stronger hydrogen bonds than the other mixtures.

Using the obtained interaction parameters, the viscosity deviations were obtained via the following relation:

$$\Delta\eta = \eta - (x_1\eta_1 + x_2\eta_2) \quad (7)$$

for the binary mixtures and applying eq 5. The results of such calculations are listed in columns 4 and 5 of Table 4. As this table shows, the relative viscosity deviations (calculated via eq 7) are rarely more than 1. Figure 2a–c shows the obtained viscosity deviations for the binary mixtures. As Figure 2 shows, the viscosity deviations of all binary mixtures under study are negative in the entire composition range and become less negative with increasing temperature.

Table 3. Parameters of McAllister Equation and the Standard Deviations, σ(%), in Correlating the Viscosities of Mixtures in the Temperature Range of (293.15 to 333.15) K

	McAllister eq			
binary systems	T/K	η_{12}/mPa·s	η_{21}/mPa·s	σ/%
$x_1$isobutanol + $x_2$1-propanol	293.15	3.77	3.01	0.49
	303.15	2.68	2.20	0.18
	313.15	1.94	1.55	0.39
	323.15	1.47	1.20	0.51
	333.15	1.01	0.78	0.62
$x_1$isobutanol + $x_2$2-propanol	293.15	4.21	3.14	0.11
	303.15	3.01	2.31	0.23
	313.15	2.17	1.64	0.52
	323.15	1.66	1.30	0.58
	333.15	1.17	0.90	0.58
$x_1$3-amino-1-propanol + $x_2$1-propanol	293.15	22.91	7.67	0.15
	303.15	14.02	4.91	1.07
	313.15	9.37	4.01	2.95
	323.15	7.11	2.75	0.16
	333.15	5.32	1.50	0.15

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Table 4. Experimental Density, ρ, Excess Molar Volume, V_m^E, Viscosity, η, Viscosity Deviation, $\Delta\eta$, and Standard Deviation in the Viscosity, σ (%), for the Mixtures at Given Temperatures and Pressure of 0.1 MPa, over Entire Composition Range[a]

x_1	ρ/g·cm^{-3}	V_m^E/cm^3·mol^{-1}	η/mPa·s	$\Delta\eta$/mPa·s	σ/%
x_1Isobutanol + $x_2$1-Propanol T/K = 293.15					
0.1038	0.80339	−0.0037	2.147	−0.121	0.34
0.1962	0.80324	−0.0074	2.269	−0.186	0.13
0.2944	0.80309	−0.0115	2.413	−0.242	0.05
0.4058	0.80291	−0.0144	2.594	−0.287	0.17
0.5040	0.80275	−0.0161	2.768	−0.312	0.17
0.6041	0.80258	−0.0164	2.961	−0.323	0.04
0.7019	0.80241	−0.0155	3.172	−0.310	0.13
0.8072	0.80221	−0.0118	3.452	−0.244	0.10
T/K = 303.15					
0.1038	0.79539	−0.0043	1.586	−0.069	0.04
0.1962	0.79527	−0.0080	1.657	−0.124	0.02
0.2944	0.79515	−0.0122	1.744	−0.171	0.04
0.4058	0.79501	−0.0159	1.855	−0.211	0.01
0.5040	0.79488	−0.0179	1.967	−0.233	0.05
0.6041	0.79474	−0.0185	2.099	−0.238	0.08
0.7019	0.79459	−0.0171	2.253	−0.218	0.04
0.8072	0.79441	−0.0127	2.448	−0.166	0.08
0.8996	0.79424	−0.0067	2.643	−0.097	0.12
T/K = 313.15					
0.1038	0.78725	−0.0054	1.079	−0.050	0.07
0.1962	0.78716	0.0096	1.140	−0.088	0.12
0.2944	0.78707	0.0143	1.210	−0.124	0.08
0.4058	0.78696	0.0184	1.297	−0.157	0.02
0.5040	0.78686	0.0211	1.382	−0.177	0.16
0.6041	0.78674	0.0215	1.487	−0.179	0.18
0.7019	0.78661	0.0198	1.611	−0.160	0.00
0.8072	0.78645	0.0151	1.767	−0.117	0.20
0.8996	0.78629	0.0080	1.914	−0.069	0.17
T/K = 323.15					
0.1038	0.77891	−0.0061	0.835	−0.037	0.04
0.1962	0.77885	0.0115	0.880	−0.064	0.15
0.2944	0.77879	0.0173	0.930	−0.092	0.12
0.4058	0.77871	0.0223	0.991	−0.118	0.02
0.5040	0.77862	0.0242	1.052	−0.135	0.18
0.6041	0.77852	0.0248	1.126	−0.139	0.23
0.7019	0.77841	0.0235	1.217	−0.125	0.05
0.8072	0.77826	0.0179	1.335	−0.090	0.25
0.8996	0.77811	0.0101	1.446	−0.051	0.27
T/K = 333.15					
0.1038	0.77034	0.0078	0.508	−0.030	0.05
0.1962	0.77031	0.0152	0.545	−0.053	0.14
0.2944	0.77027	0.0220	0.588	−0.074	0.15
0.4058	0.77020	0.0267	0.641	−0.095	0.01
0.5040	0.77013	0.0297	0.693	−0.107	0.17
0.6041	0.77004	0.0302	0.753	−0.113	0.35
0.7019	0.76994	0.0289	0.830	−0.100	0.04
0.8072	0.76980	0.0230	0.928	−0.071	0.32
0.8996	0.76964	0.0127	1.018	−0.041	0.28
x_1Isobutanol + $x_2$2-Propanol T/K = 293.15					
0.1495	0.78829	0.0055	2.450	−0.170	0.06
0.2001	0.78925	0.0079	2.498	−0.209	0.05
0.3000	0.79109	0.0125	2.621	−0.259	0.03
0.4249	0.79326	0.0150	2.810	−0.285	0.04
0.5189	0.79480	0.0141	2.976	−0.281	0.01
0.6202	0.79638	0.0109	3.184	−0.248	0.03
0.7166	0.79783	0.0079	3.395	−0.203	0.02
0.8005	0.79906	0.0064	3.594	−0.149	0.03
0.9001	0.80047	0.0041	3.838	−0.077	0.03
T/K = 303.15					
0.1495	0.77993	0.0061	1.817	−0.112	0.16
0.2001	0.78093	0.0085	1.839	−0.147	0.03
0.3000	0.78285	0.0133	1.907	−0.190	0.03
0.4249	0.78512	0.0165	2.021	−0.215	0.10
0.5189	0.78673	0.0157	2.131	−0.210	0.08
0.6202	0.78838	0.0122	2.271	−0.183	0.01
0.7166	0.78990	0.0096	2.417	−0.144	0.08
0.8005	0.79118	0.0074	2.547	−0.107	0.04
0.9001	0.79265	0.0045	2.709	−0.057	0.00
T/K = 313.15					
0.1495	0.77129	−0.0068	1.259	−0.074	0.30
0.2001	0.77234	−0.0095	1.280	−0.098	0.19
0.3000	0.77435	−0.0142	1.331	−0.136	0.07
0.4249	0.77674	−0.0185	1.418	−0.160	0.26
0.5189	0.77843	−0.0177	1.505	−0.157	0.19
0.6202	0.78017	−0.0149	1.617	−0.136	0.00
0.7166	0.78176	−0.0115	1.732	−0.107	0.11
0.8005	0.78310	−0.0086	1.837	−0.076	0.15
0.9001	0.78464	−0.0050	1.963	−0.039	0.09
T/K = 323.15					
0.1495	0.76229	−0.0079	0.983	−0.050	0.29
0.2001	0.76340	−0.0112	0.999	−0.066	0.23
0.3000	0.76553	−0.0174	1.035	−0.094	0.05
0.4249	0.76804	−0.0208	1.095	−0.114	0.31
0.5189	0.76983	−0.0206	1.158	−0.111	0.20
0.6202	0.77167	−0.0180	1.237	−0.097	0.01
0.7166	0.77335	−0.0144	1.320	−0.075	0.15
0.8005	0.77476	−0.0106	1.394	−0.054	0.17
0.9001	0.77638	−0.0059	1.483	−0.030	0.07
T/K = 333.15					
0.1495	0.75287	−0.0106	0.648	−0.034	0.29
0.2001	0.75405	−0.0146	0.663	−0.046	0.19
0.3000	0.75631	−0.0216	0.696	−0.064	0.01
0.4249	0.75897	−0.0251	0.745	−0.080	0.31
0.5189	0.76087	−0.0250	0.794	−0.080	0.23
0.6202	0.76282	−0.0219	0.857	−0.070	0.00
0.7166	0.76460	−0.0176	0.921	−0.056	0.14
0.8005	0.76609	−0.0126	0.979	−0.041	0.16
0.9001	0.76781	−0.0074	1.051	−0.022	0.12
$x_1$3-Amino-1-propanol + $x_2$1-Propanol T/K = 293.15					
0.1088	0.82673	−0.2568	2.978	−3.256	0.56
0.2019	0.84591	−0.4154	4.164	−5.644	0.19
0.2993	0.86553	−0.5405	5.873	−7.675	0.21
0.4099	0.88682	−0.5988	8.435	−9.361	0.06
0.5002	0.90378	−0.6145	11.256	−10.01	0.13
0.6014	0.92234	−0.5993	15.347	−9.805	0.30
0.6995	0.93959	−0.5323	20.076	−8.841	0.01
0.8091	0.95811	−0.4049	26.442	−6.686	0.33
0.9003	0.97264	−0.2401	32.707	−3.918	0.30
T/K = 303.15					
0.1088	0.81868	−0.2638	2.081	−1.876	0.82
0.2019	0.83785	−0.4261	2.839	−3.210	0.11
0.2993	0.85743	−0.5510	3.890	−4.347	0.32
0.4099	0.87870	−0.6090	5.443	−5.279	0.25
0.5002	0.89567	−0.6256	7.040	−5.711	0.13
0.6014	0.91425	−0.6109	9.477	−5.549	0.23
0.6995	0.93151	−0.5421	12.288	−4.942	0.12
0.8091	0.95009	−0.4152	15.930	−3.763	0.32
0.9003	0.96464	−0.2469	19.523	−2.217	0.33

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Table 4. continued

x_1	ρ/g·cm^{-3}	V_m^E/cm^3·mol^{-1}	η/mPa·s	$\Delta\eta$/mPa·s	σ/%
		T/K = 313.15			
0.1088	0.81049	−0.2704	1.401	−1.172	2.67
0.2019	0.82965	−0.4359	2.061	−1.843	0.14
0.2993	0.84923	−0.5635	2.864	−2.431	0.81
0.4099	0.87051	−0.6229	3.970	−2.907	0.61
0.5002	0.88749	−0.6395	5.050	−3.118	0.12
0.6014	0.90608	−0.6235	6.590	−3.025	0.15
0.6995	0.92340	−0.5561	8.276	−2.741	0.25
0.8091	0.94203	−0.4277	10.504	−2.080	0.45
0.9003	0.95659	−0.2542	12.627	−1.260	0.43
		T/K = 323.15			
0.1088	0.80216	−0.2810	0.999	−0.817	4.67
0.2019	0.82133	−0.4507	1.474	−1.220	0.85
0.2993	0.84093	−0.5817	2.110	−1.503	1.43
0.4099	0.86222	−0.6411	2.950	−1.705	1.86
0.5002	0.87921	−0.6566	3.657	−1.851	0.57
0.6014	0.8978	−0.6371	4.685	−1.777	0.05
0.6995	0.91521	−0.5724	5.816	−1.570	0.55
0.8091	0.93393	−0.4443	7.232	−1.189	1.07
0.9003	0.94849	−0.2631	8.570	−0.710	0.92
		T/K = 333.15			
0.1088	0.79363	−0.2936	0.579	−0.598	5.09
0.2019	0.81286	−0.4713	0.846	−0.935	1.69
0.2993	0.83249	−0.6053	1.266	−1.147	1.60
0.4099	0.85384	−0.6675	1.828	−1.303	2.08
0.5002	0.87085	−0.6811	2.352	−1.365	1.09
0.6014	0.88948	−0.6596	3.105	−1.270	0.45
0.6995	0.90701	−0.5984	3.907	−1.105	0.71
0.8091	0.92577	−0.4643	4.917	−0.806	1.55
0.9003	0.94036	−0.2760	5.829	−0.486	1.54

[a]Standard uncertainties u are $u(T) = \pm 0.01$ K, $u(\rho) = \pm 5{\cdot}10^{-5}$ g·cm^{-3}, $u(V_m^E) = \pm 1{\cdot}10^{-4}$ cm^3·mol^{-1}, and $u(\eta) = \pm 5{\cdot}10^{-2}$ mPa·s.

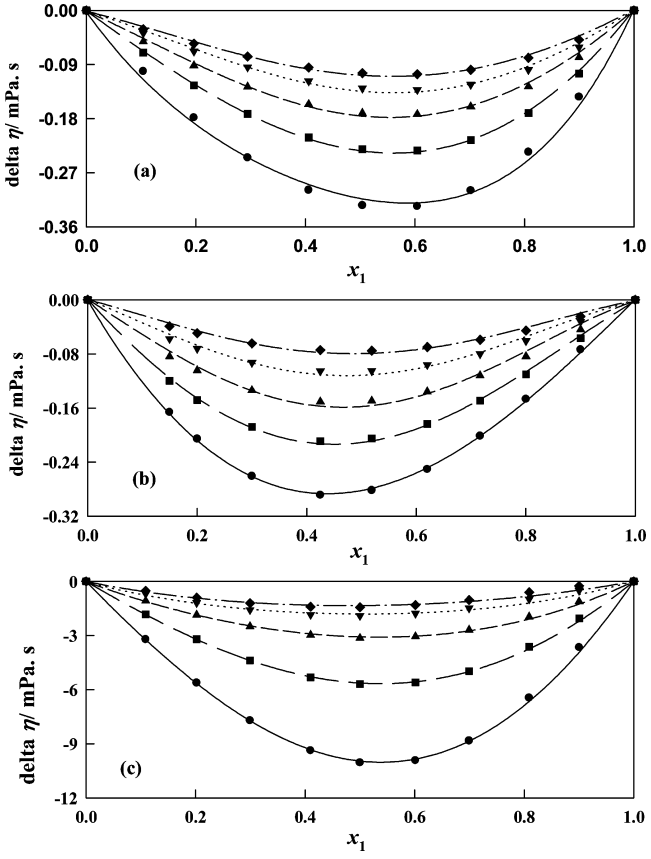

Figure 2. Viscosity deviations, $\Delta\eta$, versus mole fraction, x_1, for (a) {$x_1$isobutanol + $x_2$1-propanol}, (b) {$x_1$isobutanol + $x_2$2-propanol}, and (c) {$x_1$3-amino-1-propanol + $x_2$1-propanol} at ●,——, 293.15 K; ■,— —, 303.15 K; ▲,– – –, 313.15 K; ▼,···, 323.15 K; ♦,—•—, 333.15 K. Solid lines and symbols indicate the calculated and experimental values, respectively.

CONCLUSIONS

Density of binary mixtures of some binary mixtures of alkanols were measured in the temperature range of (293.15 to 333.15) K and over the entire composition range. The excess molar volumes and viscosity deviations for the mixtures were calculated from experimental densities and viscosities data. The obtained excess molar volumes are negative in the entire composition range and become more negative by increasing the temperature from (293.15 to 333.15) K. Increasing temperature expands the volume of the mixture so that more spaces between relative larger molecules will become available for the relative smaller molecules to fill upon mixing. This effect will pack the mixture volume.

The obtained viscosity deviations are negative over entire composition range at all temperatures for all of the binary mixtures, and become less negative with increasing temperature. The attractive interactions between components of the mixtures make weaker with increasing temperature and then they can flow easer with lower viscosity.

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Notes

The authors declare no competing financial interest.

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