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Viscosities for Binary Mixtures of 1-Bromobutane and 1,4-Dibromobutane with Isomeric Butanols at 298.15 and 313.15 K

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This paper reports viscosities and viscosity deviations for binary mixtures of 1-bromobutane and 1,4-dibromobutane with an isomer of butanol at temperatures of 298.15 and 313.15 K. Absolute viscosities were correlated using the Grunberg–Nissan equation, and kinematic viscosities by the equations of McAllister and Heric. Viscosity deviations were correlated by means of a Redlich–Kister-type equation. Viscosity deviations show negative values at both temperatures over the complete composition range.

KEY WORDS: 1-bromobutane; 1,4-dibromobutane; isomeric butanols; viscosities; viscosity deviations.

1. INTRODUCTION

Following our investigations about the thermodynamic and transport properties of binary mixtures containing butanols and haloalkanes [1–13], we report here viscosities and viscosity deviations for systems formed by 1-bromobutane or 1,4-dibromobutane plus an isomer of butanol at 298.15 and 313.15 K. The objective is to provide experimental information about the Br–OH interaction. The results are also compared with those obtained when the haloalkanes were 1-chlorobutane and 1,4-dichlorobutane [10]. No literature data have been found for these systems.

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2. EXPERIMENTAL

All liquids used were supplied by Aldrich and have the following purities: 1-butanol (better than 99.8 mol%), 2-methyl-1-propanol and 2-methyl-2-propanol (better than 99.5 mol%), and 2-butanol, 1-bromobutane, and 1,4-dibromobutane (better than 99.0 mol%). The purity of the chemicals was checked by gas chromatography and by measuring their density using an Anton Paar DMA-58 vibrating tube densimeter automatically thermostated at 298.15 ± 0.01 K. The purities obtained were considered sufficient, so no further purification was attempted.

Kinematic viscosities, ν, were obtained with the aid of an Ubbelhode viscometer and a Schott–Geräte automatic measuring unit, Model AVS-440. The accuracy of the time flow measurements was ±0.01 s and the estimated error in the kinematic viscosity was $\pm 1 \times 10^{-4}\ \mathrm{mm}^2 \cdot \mathrm{s}^{-1}$. Mole fractions of the mixtures were determined by mass and their accuracy is estimated to be less than $\pm 1 \times 10^{-4}$. Densities, ρ, required for calculating absolute viscosities ($\eta = \rho\nu$) were determined with the densimeter cited above [5, 14]. The uncertainty of density measurements was $\pm 1 \times 10^{-5}\ \mathrm{g} \cdot \mathrm{cm}^{-3}$, and that of the absolute viscosity, $\pm 1 \times 10^{-4}\ \mathrm{mPa} \cdot \mathrm{s}$. Details for calibration and procedures have been described elsewhere [15].

The experimental densities and viscosities of the pure compounds at both temperatures are listed in Table I together with literature data [16].

3. RESULTS AND DISCUSSION

Viscosity deviations were calculated from our measurements according to the equation

$$\Delta\eta = \eta - \sum_{i=1}^{2} x_i \eta_i \tag{1}$$

Table I. Densities, ρ, and Viscosities, η, of Pure Compounds at 298.15 K and Comparisons, with Literature Data [16]

	ρ (g · cm^{-3})		η (mPa · s)	
Compound	Exp.	Lit.	Exp.	Lit.
1-Bromobutane	1.26589	1.2687	0.5941	0.597
1,4-Dibromobutane	1.81864		2.5794	
1-Butanol	0.80583	0.80575	2.5562	2.5710
2-Butanol	0.80244	0.80241	3.0596	2.998
2-Methyl-1-propanol	0.79783	0.7978	3.3603	3.3330
2-Methyl-2-propanol	0.78074	0.7812	4.4126	4.438

Table II. Experimental Kinematic Viscosities, ν, Absolute Viscosities, η, and Viscosity Deviations, $\Delta\eta$, of Binary Mixtures 1-Bromobutane or 1,4-Dibromobutane (1) with an Isomeric Butanol (2) at 298.15 and 313.15 K

x_1	ν $(\text{mm}^2\cdot\text{s}^1)$	η $(\text{mPa}\cdot\text{s})$	$\Delta\eta$ $(\text{mPa}\cdot\text{s})$	x_1	ν $(\text{mm}^2\cdot\text{s}^1)$	η $(\text{mPa}\cdot\text{s})$	$\Delta\eta$ $(\text{mPa}\cdot\text{s})$
1-Bromobutane (1) + 1-butanol (2) at 298.15 K							
0.0997	2.3654	2.0313	−0.3293	0.6019	0.7452	0.8187	−0.5565
0.2003	1.7840	1.6236	−0.5396	0.7021	0.6328	0.7228	−0.4558
0.3005	1.3896	1.3333	−0.6333	0.7999	0.5540	0.6557	−0.3310
0.4004	1.0992	1.1070	−0.6636	0.9020	0.4984	0.6110	−0.1754
0.5075	0.8826	0.9324	−0.6280				
1-Bromobutane (1) + 2-butanol (2) at 298.15 K							
0.1043	2.2998	1.9703	−0.8322	0.6033	0.6659	0.7287	−0.8434
0.1998	1.6156	1.4619	−1.1051	0.7047	0.5811	0.6619	−0.6602
0.2999	1.2056	1.1500	−1.1702	0.8013	0.5262	0.6214	−0.4626
0.4072	0.9344	0.9389	−1.1167	0.9011	0.4860	0.5947	−0.2432
0.5011	0.7798	0.8174	−1.0067				
1-Bromobutane (1) + 2-methyl-1-propanol (2) at 298.15 K							
0.1015	2.8080	2.3920	−0.6876	0.6048	0.7474	0.8186	−0.8687
0.2014	1.9817	1.7899	−1.0133	0.7064	0.6370	0.7265	−0.6798
0.3007	1.4649	1.3956	−1.1329	0.8080	0.5579	0.6609	−0.4643
0.4045	1.1149	1.1180	−1.1234	0.9052	0.5016	0.6150	−0.2413
0.4997	0.9055	0.9484	−1.0297				
1-Bromobutane (1) + 2-methyl-2-propanol (2) at 298.15 K							
0.0476	3.8546	3.1049	−1.1259	0.5055	0.7970	0.8248	−1.6575
0.1052	2.7118	2.2650	−1.7459	0.6089	0.6791	0.7364	−1.3511
0.1507	2.1537	1.8490	−1.9881	0.7021	0.6000	0.6770	−1.0546
0.2044	1.7247	1.5278	−2.1043	0.8039	0.5393	0.6340	−0.7089
0.3074	1.2303	1.1536	−2.0852	0.9034	0.4952	0.6049	−0.3581
0.4040	0.9732	0.9590	−1.9109				
1-Bromobutane (1) + 1-butanol (2) at 313.15 K							
0.0997	1.6802	1.4205	−0.2098	0.6019	0.6037	0.6514	−0.3503
0.2003	1.3045	1.1681	−0.3363	0.7021	0.5241	0.5877	−0.2885
0.3005	1.0445	0.9856	−0.3934	0.7999	0.4686	0.5444	−0.2093
0.4004	0.8509	0.8423	−0.4116	0.9020	0.4259	0.5125	−0.1134
0.5075	0.7004	0.7270	−0.3929				
1-Bromobutane (1) + 2-butanol (2) at 313.15 K							
0.1043	1.5079	1.2702	−0.3815	0.6033	0.5416	0.5816	−0.4302
0.1998	1.1268	1.0018	−0.5274	0.7047	0.4876	0.5450	−0.3369
0.2999	0.8857	0.8296	−0.5713	0.8013	0.4464	0.5173	−0.2407
0.4072	0.7191	0.7093	−0.5540	0.9011	0.4161	0.4996	−0.1304
0.5011	0.6215	0.6394	−0.5035				

Table II. *(Continued)*

x_1	ν ($\mathrm{mm}^2\cdot\mathrm{s}^1$)	η ($\mathrm{mPa}\cdot\mathrm{s}$)	$\Delta\eta$ ($\mathrm{mPa}\cdot\mathrm{s}$)	x_1	ν ($\mathrm{mm}^2\cdot\mathrm{s}^1$)	η ($\mathrm{mPa}\cdot\mathrm{s}$)	$\Delta\eta$ ($\mathrm{mPa}\cdot\mathrm{s}$)
1-Bromobutane (1) + 2-methyl-1-propanol (2) at 313.15 K							
0.1015	1.8738	1.5711	−0.3600	0.6048	0.6016	0.6470	−0.4843
0.2014	1.3831	1.2288	−0.5436	0.7064	0.5295	0.5927	−0.3771
0.3007	1.0701	1.0022	−0.6124	0.8080	0.4662	0.5420	−0.2664
0.4045	0.8469	0.8344	−0.6152	0.9052	0.4226	0.5085	−0.1454
0.4997	0.7097	0.7301	−0.5682				
1-Bromobutane (1) + 2-methyl-2-propanol (2) at 313.15 K							
0.0476	2.0424	1.6118	−0.4012	0.5055	0.6248	0.6338	−0.6533
0.1052	1.5931	1.3037	−0.6180	0.6089	0.5443	0.5786	−0.5446
0.1507	1.3510	1.1365	−0.7131	0.7021	0.4923	0.5445	−0.4310
0.2044	1.1525	1.0004	−0.7640	0.8039	0.4483	0.5167	−0.2974
0.3074	0.8850	0.8132	−0.7879	0.9034	0.4168	0.4993	−0.1571
0.4040	0.7357	0.7106	−0.7374				
1,4-Dibromobutane (1) + 1-butanol (2) at 298.15 K							
0.0994	2.5086	2.3390	−0.2195	0.6014	1.3860	2.0437	−0.5264
0.1993	2.0616	2.1696	−0.3912	0.6981	1.3346	2.0871	−0.4852
0.2992	1.7772	2.0719	−0.4912	0.7994	1.3185	2.1797	−0.3951
0.3995	1.5918	2.0275	−0.5380	0.8954	1.3262	2.2997	−0.2772
0.4938	1.4748	2.0206	−0.5470				
1,4-Dibromobutane (1) + 2-butanol (2) at 298.15 K							
0.1040	2.4336	2.2717	−0.7380	0.6014	1.2959	1.9039	−0.8669
0.2000	1.8922	1.9826	−0.9809	0.6963	1.2567	1.9571	−0.7681
0.2976	1.6090	1.8635	−1.0532	0.8040	1.2642	2.0898	−0.5837
0.4019	1.4375	1.8260	−1.0406	0.8917	1.3102	2.2643	−0.3671
0.4951	1.3421	1.8327	−0.9891				
1,4-Dibromobutane (1) + 2-methyl-1-propanol (2) at 298.15 K							
0.1014	3.0012	2.7821	−0.4990	0.5929	1.4514	2.1219	−0.7754
0.2001	2.3323	2.4392	−0.7648	0.7002	1.3725	2.1443	−0.6692
0.3003	1.9468	2.2586	−0.8672	0.8006	1.3330	2.2020	−0.5331
0.3956	1.7182	2.1707	−0.8807	0.9027	1.3444	2.3380	−0.3173
0.4995	1.5494	2.1232	−0.8470				

Table II. *(Continued)*

x_1	ν (mm^2 · s^1)	η (mPa · s)	$\Delta\eta$ (mPa · s)	x_1	ν (mm^2 · s^1)	η (mPa · s)	$\Delta\eta$ (mPa · s)
		1,4-Dibromobutane (1) + 2-methyl-2-propanol (2) at 298.15 K					
0.0614	3.7391	3.2082	−1.0918	0.5077	1.4793	2.0147	−1.4672
0.1066	3.0348	2.7729	−1.4442	0.6054	1.3911	2.0304	−1.2724
0.2070	2.2211	2.2958	−1.7373	0.7023	1.3337	2.0704	−1.0547
0.3046	1.8410	2.1081	−1.7460	0.8012	1.3151	2.1612	−0.7826
0.4052	1.6139	2.0254	−1.6444	0.9049	1.3365	2.3195	−0.4342
		1,4-Dibromobutane (1) + 1-butanol (2) at 313.15 K					
0.0994	1.7687	1.6244	−0.1539	0.6014	1.0476	1.5221	−0.3732
0.1993	1.4790	1.5329	−0.2687	0.6981	1.0237	1.5778	−0.3401
0.2992	1.2941	1.4859	−0.3390	0.7994	1.0178	1.6587	−0.2827
0.3995	1.1767	1.4763	−0.3720	0.8954	1.0334	1.7672	−0.1967
0.4938	1.1017	1.4870	−0.3833				
		1,4-Dibromobutane (1) + 2-butanol (2) at 313.15 K					
0.1040	1.5870	1.4569	−0.3496	0.6014	0.9708	1.4046	−0.5028
0.2000	1.2979	1.3375	−0.4885	0.6963	0.9650	1.4809	−0.4458
0.2976	1.1411	1.3001	−0.5457	0.8040	0.9808	1.5988	−0.3497
0.4019	1.0473	1.3090	−0.5579	0.8917	1.0170	1.7339	−0.2324
0.4951	0.9976	1.3409	−0.5449				
		1,4-Dibromobutane (1) + 2-methyl-1-propanol (2) at 313.15 K					
0.1014	1.9880	1.8151	−0.2668	0.5929	1.0784	1.5533	−0.4773
0.2001	1.5987	1.6466	−0.4250	0.7002	1.0390	1.5997	−0.4197
0.3003	1.3697	1.5649	−0.4962	0.8006	1.0292	1.6760	−0.3330
0.3956	1.2329	1.5341	−0.5171	0.9027	1.0484	1.7979	−0.2005
0.4995	1.1345	1.5314	−0.5090				
		1,4-Dibromobutane (1) + 2-methyl-2-propanol (2) at 313.15 K					
0.0614	2.0603	1.7333	−0.3491	0.5077	1.0704	1.4339	−0.6037
0.1066	1.8010	1.6141	−0.4636	0.6054	1.0325	1.4831	−0.5446
0.2070	1.4324	1.4533	−0.6144	0.7023	1.0109	1.5455	−0.4725
0.3046	1.2504	1.4064	−0.6515	0.8012	1.0129	1.6406	−0.3675
0.4052	1.1386	1.4045	−0.6434	0.9049	1.0474	1.7930	−0.2047

where η and η_i are the absolute viscosities (mPa · s) of the mixture and pure component i, respectively, and x_i is the mole fraction of component i. Subscript 1 is used for haloalkane, and 2 for isomeric butanol. The kinematic and absolute viscosities together with viscosity deviations are presented in Table II and shown graphically in Figs. 1–4.

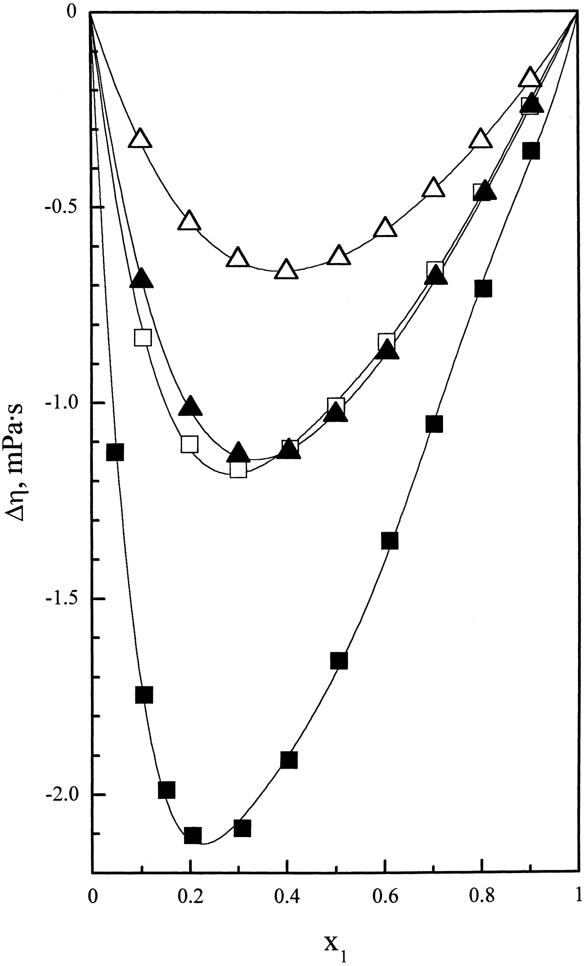

Fig. 1. Viscosity deviations of 1-bromobutane (1) + an isomer of butanol (2) at 298.15 K as a function of the mole fraction x_1: 1-butanol (△); 2-butanol (□); 2-methyl-1-propanol (▲); 2-methyl-2-propanol (■).

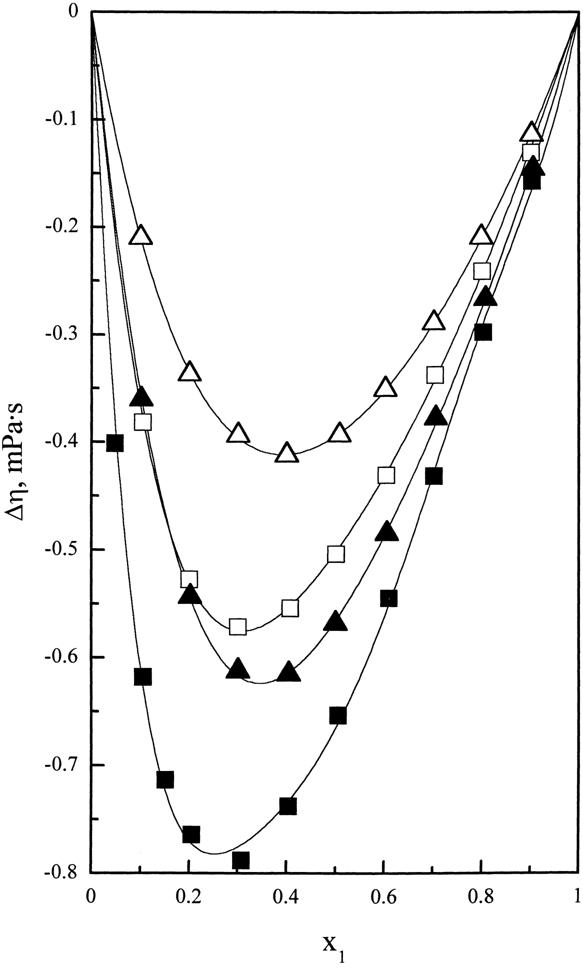

Fig. 2. Viscosity deviations of 1-bromobutane (1) + an isomer of butanol (2) at 313.15 K as a function of the mole fraction x_1: 1-butanol (△); 2-butanol (□); 2-methyl-1-propanol (▲); 2-methyl-2-propanol (■).

The Grunberg–Nissan equation [17] was used to correlate the absolute viscosity data:

$$\ln \eta = x_1 \ln \eta_1 + x_2 \ln \eta_2 + x_1 x_2 d \qquad (2)$$

where d is an interaction parameter that is a function of the nature of the components and temperature. The values of d, obtained by fitting Eq. (2)

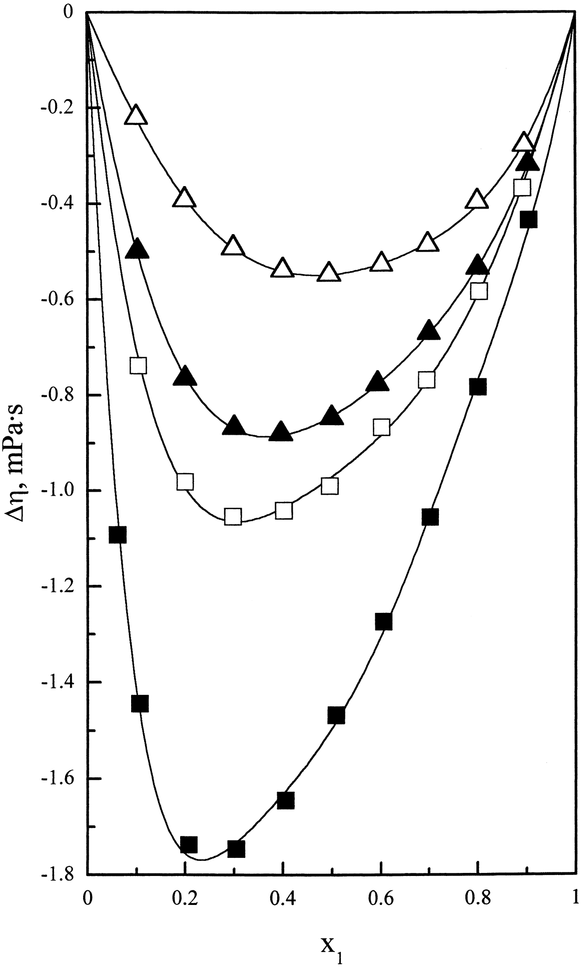

Fig. 3. Viscosity deviations of 1,4-dibromobutane (1) + an isomer of butanol (2) at 298.15 K as a function of the mole fraction x_1: 1-butanol (△); 2-butanol (□); 2-methyl-1-propanol (▲); 2-methyl-2-propanol (■).

to the viscosity data, along with the mean relative standard deviation (MRSD) between experimental and calculated absolute viscosities are given in Table III. The MRSD is expressed as a percentage, and it is defined by the following expression:

$$\mathrm{MRSD} = 100 \times \left[\frac{1}{N} \sum_{i=1}^{i=N} \left(\frac{Y_i^{\mathrm{exp}} - Y_i^{\mathrm{calc}}}{Y_i^{\mathrm{exp}}} \right)^2 \right]^{\frac{1}{2}} \tag{3}$$

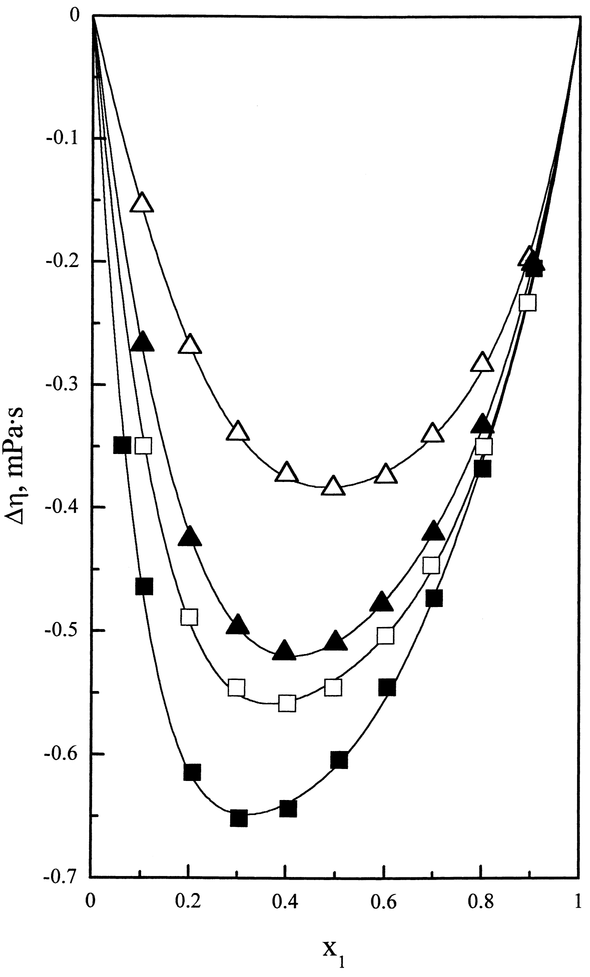

Fig. 4. Viscosity deviations of 1,4-dibromobutane (1) + an isomer of butanol (2) at 313.15 K as a function of the mole fraction x_1: 1-butanol (△); 2-butanol (□); 2-methyl-1-propanol (▲); 2-methyl-2-propanol (■).

where Y is the adjusted property and N is the number of experimental data. The obtained deviations show that this simple equation correlates the absolute viscosity data satisfactorily, especially when the mixture involves a primary butanol (1-butanol or 2-methyl-1-propanol), but this correlation is poor for systems containing 2-methyl-2-propanol. The interaction parameter is negative for all the mixtures at both temperatures. According

Table III. Interaction Parameter, d, and MRSD of Eq. (2) at Indicated Temperatures

System	$T = 298.15$ K		$T = 313.15$ K	
	d	MRSD	d	MRSD
1-Bromobutane +				
1-Butanol	−1.0795	1.30	−1.0004	0.87
2-Butanol	−2.0593	5.24	−1.6315	4.02
2-Methyl-1-propanol	−1.5990	1.83	−1.3736	1.76
2-Methyl-2-propanol	−2.9109	13.80	−2.0792	8.82
1,4-Dibromobutane +				
1-Butanol	−0.9939	0.90	−0.9418	0.82
2-Butanol	−1.8198	6.79	−1.4468	4.85
2-Methyl-1-propanol	−1.3763	2.66	−1.1993	2.08
2-Methyl-2-propanol	−2.2908	11.88	−1.5472	6.75

to Fort and Moore [18], this sign of d indicates that dispersion forces, principally the breaking of the self-association of butanols, are predominant.

The kinematic viscosities were correlated by using the following equations.

McAllister [19].

$$\ln \nu = x_1^3 \ln \nu_1 + 3x_1^2(1-x_1) \ln \nu_{12} + 3x_1(1-x_1)^2 \ln \nu_{21} + (1-x_1)^3 \ln \nu_2 - \ln\left(x_1 + \frac{M_2}{M_1}(1-x_1)\right) + 3x_1^2(1-x_1) \ln\left(\frac{2}{3} + \frac{M_2}{3M_1}\right) + 3x_1(1-x_1)^2 \ln\left(\frac{1}{3} + \frac{2M_2}{3M_1}\right) + (1-x_1)^3 \ln\left(\frac{M_2}{M_1}\right) \tag{4}$$

where ν and ν_i are the kinematic viscosity ($\text{mm}^2 \cdot \text{s}^{-1}$) of the mixture and pure component i, respectively, x_i and M_i are the mole fraction and the molecular mass of component i, and ν_{12} and ν_{21} are adjustable parameters characteristic of the system.

Heric [20].

$$\ln \nu = x_1 \ln(\nu_1 M_1) + (1-x_1) \ln(\nu_1 M_2) - \ln(x_1 M_1 + (1-x_1) M_2) + x_1(1-x_1)[\alpha_{12} + \alpha'_{12}(2x_1 - 1)] \tag{5}$$

in which α_{12} and α'_{12} are also adjustable parameters. The estimated parameters for Eqs. (4) and (5) together with the corresponding MRSD calculated

Table IV. Parameters and MRSD of Eqs. (4) and (5) at Indicated Temperatures.

		McAllister			Heric		
System	T (K)	ν_{12} ($\mathrm{mm^2 \cdot s^{-1}}$)	ν_{21} ($\mathrm{mm^2 \cdot s^{-1}}$)	MRSD	α_{12}	α'_{12}	MRSD
1-Bromobutane +							
1-Butanol	298.15	0.5674	1.1911	0.41	−1.0600	−0.1653	0.41
2-Butanol		0.5767	0.7381	1.71	−2.0295	0.6690	1.71
2-Methyl-1-propanol		0.6022	1.0545	0.40	−1.5786	0.2486	0.40
2-Methyl-2-propanol		0.7229	0.5179	4.23	−2.8122	1.7361	4.23
1-Butanol	313.15	0.4810	0.8931	0.43	−0.9765	−0.0881	0.43
2-Butanol		0.4819	0.6036	1.36	−1.5958	0.5137	1.36
2-Methyl-1-propanol		0.4998	0.8082	0.89	−1.3480	0.2124	0.89
2-Methyl-2-propanol		0.5421	0.4944	3.46	−2.0017	1.0839	3.46
1,4-Dibromobutane +							
1-Butanol	298.15	1.2004	1.5441	0.89	−0.9607	−0.0165	0.89
2-Butanol		1.2754	1.0139	3.05	−1.7767	0.7973	3.05
2-Methyl-1-propanol		1.2865	1.4796	1.59	−1.3461	0.2931	1.59
2-Methyl-2-propanol		1.5158	0.9261	5.46	−2.2441	1.3890	5.46
1-Butanol	313.15	0.9295	1.1267	0.84	−0.9051	0.0151	0.84
2-Butanol		0.9530	0.8080	2.27	−1.4007	0.5628	2.27
2-Methyl-1-propanol		0.9768	1.0851	1.14	−1.1663	0.2391	1.14
2-Methyl-2-propanol		1.0615	0.8159	3.19	−1.5074	0.8041	3.19

by Eq. (3) are listed in Table IV. Both equations with two parameters correlate very well the kinematic viscosity data, especially for mixtures containing primary butanols, and they give about the same MRSD values.

The values of Δh for the binary mixtures at both temperatures were fitted to a Redlich–Kister polynomial equation [21]:

$$\Delta\eta = x_1(1-x_1)\sum_{p=0}^{p} A_p(2x_1-1)^p \tag{6}$$

where x_1 denotes the mole fraction of bromoalkane, and A_p's are adjustable parameters. Table V lists the parameters A_p and the standard deviations $\sigma(\Delta\eta)$, defined as

$$\sigma(\Delta\eta) = \left[\frac{\sum(\Delta\eta_{\mathrm{exp}} - \Delta\eta_{\mathrm{calc}})^2}{n-p}\right]^{\frac{1}{2}} \tag{7}$$

where n is the number of experimental data and p is the number of parameters.

Table V. Coefficients and Standard Deviations of Eq. (6) at Indicated Temperatures

System	T (K)	A_0 (mPa · s)	A_1 (mPa · s)	A_2 (mPa · s)	A_3 (mPa · s)	A_4 (mPa · s)	$\sigma(\Delta\eta)$ (mPa · s)
1-Bromobutane +							
1-Butanol	298.15	−2.5258	1.0690	−0.4951	−0.0104		0.0029
2-Butanol		−3.9899	2.6991	−2.7022	1.8548		0.0132
2-Methyl-1-propanol		−4.1031	2.5245	−1.6132	0.6607		0.0050
2-Methyl-2-propanol		−6.7472	4.9775	−3.0908	6.6552	−7.2708	0.0340
1-Butanol	313.15	−1.5751	0.6161	−0.3567	0.0814		0.0017
2-Butanol		−2.0073	1.2695	−1.1500	0.6099		0.0044
2-Methyl-1-propanol		−2.2614	1.3370	−0.8286	0.1261		0.0040
2-Methyl-2-propanol		−2.6630	1.7213	−0.8628	2.0946	−2.7166	0.0147
1,4-Dibromobutane +							
1-Butanol	298.15	−2.1875	0.1924	−0.8000	−0.7410		0.0054
2-Butanol		−3.8737	1.5166	−2.9990	1.6024		0.0146
2-Methyl-1-propanol		−3.3697	1.1735	−1.8624	0.0300		0.0036
2-Methyl-2-propanol		−5.9704	3.2179	−3.2250	5.3022	−5.9084	0.0267
1-Butanol	313.15	−1.5282	0.0667	−0.5735	−0.4497		0.0034
2-Butanol		−2.1526	0.5369	−1.3923	0.4762		0.0054
2-Methyl-1-propanol		−2.0331	0.4740	−0.9147	−0.0661		0.0024
2-Methyl-2-propanol		−2.4359	0.8304	−1.2435	1.3155	−1.2948	0.0107

Viscosity deviations are negative over the complete composition range at both temperatures. From the viewpoint of a defined bromoalkane the most negative values correspond to the system containing 2-methyl-2-propanol and the least negative to those with 1-butanol. The mixtures with 2-butanol and 2-methyl-1-propanol show similar $\Delta\eta$ values, especially with the monobrominated alkane. In the systems containing 1,4-dibromobutane, those with the branched primary butanol always show viscosity deviations somewhat less negative. For a given alcoholic isomer, mixtures containing the monobrominated alkane reveal values for the viscosity deviations noticeably more negative than those corresponding to the α, ω-dibrominated mixture.

In all cases, an increase in the temperature gives viscosity deviations less negative, with the effect more pronounced for the systems involving 2-methyl-2-propanol.

The results reported here can be compared with those obtained when the halogenated derivatives contain chlorine atoms [10] instead of bromine ones. This comparison shows similar behavior for both kinds of compounds, with the only difference that $\Delta\eta$ values are slightly less negative in the case of mixures containing brominated derivatives. The intermolecular forces that determine the observed behavior have been considered in detail previously [8, 9]. The substitution of bromine for chlorine must yield both different steric effects and different strengths in the halogen–OH interaction. However, the behavior observed for the chlorinated compounds is not significantly altered.

As a matter of fact, the viscometric behavior of mixtures containing a fixed isomer of butanol is very similarly independent of the halogenated derivative, such as monohalogenated [8–11, 13] or α,ω-dihaloalkane [7, 10, 12], with which the alcohol is mixed. This situation had been pointed out for other properties of these systems, such as the excess volume [1–6, 8, 9, 11, 13]. Thus, it can be concluded that the main effect determining the behavior of the mixtures is the change produced in the self-associated structure of isomeric butanols.

REFERENCES

1. J. Pardo, V. Rodríguez, C. Lafuente, F. M. Royo, and J. S. Urieta, *J. Chem. Thermodyn.* **25**:373 (1993).
2. H. Artigas, J. Santafé, M. C. López, F. M. Royo, and J. S. Urieta, *J. Chem. Thermodyn.* **25**:1403 (1993).
3. C. Lafuente, J. Pardo, V. Rodríguez, F. M. Royo, and J. S. Urieta, *J. Chem. Eng. Data* **38**:554 (1993).
4. C. Lafuente, V. Rodríguez, M. C. López, F. M. Royo, and J. S. Urieta, *J. Sol. Chem.* **23**:561 (1994).
5. H. Artigas, C. Lafuente, V. Rodríguez, F. M. Royo, and J. S. Urieta, *J. Chem. Thermodyn.* **26**:151 (1994).
6. V. Rodríguez, H. Artigas, C. Lafuente, F. M. Royo, and J. S. Urieta, *J. Chem. Thermodyn.* **26**:1173 (1994).
7. C. Lafuente, H. Artigas, M. C. López, F. M. Royo, and J. S. Urieta, *J. Mol. Liq.* **62**:199 (1994).
8. P. Cea, C. Lafuente, H. Artigas, F. M. Royo, and J. S. Urieta, *Can. J. Chem.* **72**:1921 (1994).
9. P. Cea, C. Lafuente, J. P. Morand, F. M. Royo, and J. S. Urieta, *Phys. Chem. Liq.* **29**:69 (1995).
10. C. Lafuente, H. Artigas, J. Pardo, F. M. Royo, and J. S. Urieta, *J. Sol. Chem.* **25**:303 (1996).
11. H. Artigas, P. Cea, J. Pardo, F. M. Royo, and J. S. Urieta, *Int. J. Thermophys.* **17**:347 (1996).
12. L. Mussari, M. Postigo, C. Lafuente, F. M. Royo, and J. S. Urieta, *J. Chem. Eng. Data* **45**:86 (corrected on 409) (2000).
13. C. Infante, H. Artigas, C. Lafuente, A. M. Mainar, and J. S. Urieta, *Phys. Chem. Liq.* (in press).
14. V. Rodríguez, *Thesis* (University of Zaragoza, Zaragoza, Spain, 1997).
15. D. Blasco, C. Lafuente, J. Santafé, F. M. Royo, and J. S. Urieta, *Thermochim. Acta* **230**:55 (1993).
16. J. A. Riddick, W. B. Bunger, and T. K. Sakano, *Organic Solvents, Techniques of Chemistry, Vol. 2* (Wiley, New York, 1986).

17. L. Grunberg and A. H. Nissan, *Nature* **164**:799 (1949).
18. R. J. Fort and W. R. Moore, *Trans. Faraday Soc.* **62**:1112 (1966).
19. R. A. McAllister, *AIChE J.* **6**:427 (1960).
20. E. L. Heric, *J. Chem. Eng. Data* **11**:66 (1966).
21. O. Redlich and A. T. Kister, *Ind. Eng. Chem.* **40**:345 (1948).