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Viscosity and Density of Dilute Aqueous Solutions of 1-Pentanol and 2-Methyl-2-butanol

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Density and viscosity of dilute aqueous solutions of 1-pentanol and 2-methyl-2-butanol, for the mole fraction of alcohol ranging from 0 to 0.0036 and temperatures ranging from 10 °C to 50 °C, have been measured. The viscosity data were correlated by the Grunberg−Nissan equation and the Heric equation.

Introduction

It is well-known that the solubility of 1-pentanol and 2-methyl-2-butanol in water is very small. For example, the mole fraction solubility of 1-pentanol in water is 0.004 217 at 30 °C. (Bulter et al., 1933; Ginnings and Baum, 1937; Kinsochita et al., 1958). In this paper we present density and viscosity measurements for the dilute aqueous solutions of 1-pentanol and 2-methyl-2-butanol. To the best of our knowledge, there are neither density nor viscosity measurements for the systems water + 1-pentanol and water + 2-methyl-2-butanol available in the literature.

Experimental Section

Reagent grade 1-pentanol (better than 98.5% purity) and 2-methyl-2-butanol (better than 99.5% purity) were obtained from Merck. Water was purified in a Barnstead NANOpure II system with resistivity better than 17.8 M Ω·cm. The comparison of measured density, refractive index, and viscosity of 1-pentanol, 2-methyl-2-butanol, and water with literature values (TRC, 1993) at 293.15 K is shown in Table 1. The purity of 1-pentanol was further checked by gas chromatography, confirming the absence of other significant organic components, so no further purification was attempted.

Viscosity measurements were performed in an Ubbelohde suspended-level glass-capillary viscometer supplied by Schott-Geräte (Hofheim a. Ts., Germany) along with a Schott-Geräte automatic measuring unit model AVS-310 (Hofheim a. Ts., Germany). The temperature was kept constant within ±0.005 K by a computer-controlled water-bath thermostat. The accuracy of the time for flow measurements of Schott-Geräte AVS-310 was within ±0.01 s. At least six times flow measurements were performed for each composition and temperature, and the results were determined by averaging over these six measurements. According to the variation of our experimental results of flow times, the estimated uncertainty in the kinematic viscosity measurements was less than 0.33%. All the solutions were prepared by mass with deviations of less than 0.1% from the reported concentrations.

For the streamline flow of a Newtonian liquid at steady state, with no slip at the wall, the absolute viscosity η is related to the flow rate Q by means of the Poiseuille equation. Allowance for conversion of some of the total pressure head ΔP into kinetic energy gives the following expression for the kinematic viscosity ν (Dinsdale and Moore, 1962)

Table 1. Comparison of the Experimental Results and Literature Data (TRC, 1993) of Densities, ρ, Refractive Index, n_D, and Viscosities, η, of the Pure Compounds at 293.15 K

	ρ/g·cm^{-3}		n_D		η/mPa·s	
compound	exptl	lit.	exptl	lit.	exptl	lit.
1-pentanol	0.814 53	0.815 1	1.4096	1.4100	4.0606	4.0608
2-methyl-2-butanol	0.809 99	0.809 6	1.4049	1.4049	4.3817	4.3760
water	0.998 21	0.998 205 8	1.3330	1.33299	0.9943	1.0020

$$\nu = \frac{\eta}{\rho} = \frac{\pi r^4 \Delta P}{8\rho Q L} - \frac{cQ}{8\pi L} \qquad (1)$$

where ρ is the liquid density, r the capillary radius, L the effective capillary length, and c the empirical coefficient of the last equation. Since the flow rate Q is inversely proportional to the flow time t, the last equation can be written in terms of time as

$$\nu = At - \frac{B}{t} \qquad (2)$$

where constants A and B were determined by careful calibration. Two pure components, water and ethanol, were used to calibrate the Ubbelohde viscometer by measuring the flow times of above fluids at nine different temperatures (10, 15, 20, 25, 30, 35, 40, 45, and 50 °C). All the kinematic viscosities of both calibration fluids were adopted from the literature (TRC, 1993), and the linear regression analysis of eq 2 yielded constants $A = 0.004\,932$ and $B = 0.3359$ with a correlation coefficient of better than 0.9999.

Since the absolute viscosity η is defined by $\eta = \nu\rho$, the density of a mixture should be measured to determine its absolute viscosity η. Densities were measured with a vibrating tube density meter (Anton-Paar DMA-58, Austria) equipped with a thermostat, its stability within ±0.01 K. The calibration of the density meter was carried out with water (purified) and dry air at each temperature. The accuracy of density measurements was ±0.000 02 g/cm^3.

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Table 2. Experimental Results of Kinematic Viscosity, Density, and Absolute Viscosity for Water (1) + 1-Pentanol (2)

t/°C	ν/mm^2·s^{-1}	ρ/g·cm^{-3}	η/mPa·s	t/°C	ν/mm^2·s^{-1}	ρ/g·cm^{-3}	η/mPa·s	t/°C	ν/mm^2·s^{-1}	ρ/g·cm^{-3}	η/mPa·s
$x_2 = 0.000$											
10	1.2933	0.999 70	1.2929	25	0.8879	0.997 05	0.8853	40	0.6605	0.992 22	0.6553
15	1.1286	0.999 10	1.1275	30	0.7985	0.995 65	0.7950	45	0.6066	0.990 22	0.6007
20	0.9961	0.998 21	0.9943	35	0.7226	0.994 03	0.7183	50	0.5605	0.988 04	0.5538
$x_2 = 3.998 \times 10^{-4}$											
10	1.3152	0.999 38	1.3144	25	0.9004	0.996 77	0.8975	40	0.6690	0.991 97	0.6637
15	1.1466	0.998 80	1.1452	30	0.8094	0.995 45	0.8057	45	0.6143	0.989 96	0.6082
20	1.0109	0.997 91	1.0088	35	0.7333	0.993 86	0.7288	50	0.5673	0.987 69	0.5604
$x_2 = 7.972 \times 10^{-4}$											
10	1.3261	0.999 13	1.3249	25	0.9063	0.996 43	0.9031	40	0.6741	0.991 54	0.6684
15	1.1551	0.998 52	1.1534	30	0.8156	0.995 01	0.8115	45	0.6185	0.989 49	0.6120
20	1.0181	0.997 59	1.0156	35	0.7393	0.993 47	0.7345	50	0.5716	0.987 36	0.5643
$x_2 = 1.180 \times 10^{-3}$											
10	1.3416	0.998 87	1.3401	25	0.9143	0.996 18	0.9108	40	0.6765	0.991 29	0.6706
15	1.1676	0.998 26	1.1656	30	0.8206	0.994 74	0.8162	45	0.6204	0.989 28	0.6138
20	1.0280	0.997 30	1.0252	35	0.7423	0.993 11	0.7371	50	0.5722	0.987 10	0.5649
$x_2 = 1.580 \times 10^{-3}$											
10	1.3531	0.998 64	1.3512	25	0.9208	0.995 91	0.9170	40	0.6816	0.990 95	0.6754
15	1.1766	0.998 03	1.1743	30	0.8263	0.994 44	0.8218	45	0.6250	0.988 93	0.6181
20	1.0355	0.997 03	1.0324	35	0.7479	0.992 80	0.7425	50	0.5766	0.986 73	0.5690
$x_2 = 2.007 \times 10^{-3}$											
10	1.3721	0.998 29	1.3697	25	0.9310	0.995 58	0.9269	40	0.6887	0.990 66	0.6823
15	1.1921	0.997 65	1.1893	30	0.8357	0.994 11	0.8308	45	0.6311	0.988 63	0.6239
20	1.0478	0.996 64	1.0443	35	0.7546	0.992 48	0.7489	50	0.5823	0.986 40	0.5744
$x_2 = 2.402 \times 10^{-3}$											
10	1.3857	0.998 01	1.3830	25	0.9404	0.995 26	0.9359	40	0.6924	0.990 35	0.6857
15	1.2034	0.997 37	1.2002	30	0.8424	0.993 80	0.8372	45	0.6338	0.988 30	0.6264
20	1.0581	0.996 39	1.0542	35	0.7611	0.992 16	0.7552	50	0.5842	0.986 09	0.5761
$x_2 = 2.800 \times 10^{-3}$											
10	1.3981	0.997 61	1.3947	25	0.9450	0.994 92	0.9402	40	0.6963	0.990 04	0.6894
15	1.2129	0.997 00	1.2093	30	0.8473	0.993 51	0.8418	45	0.6381	0.988 09	0.6305
20	1.0650	0.996 02	1.0608	35	0.7653	0.991 87	0.7590	50	0.5881	0.985 80	0.5798
$x_2 = 3.200 \times 10^{-3}$											
10	1.4138	0.997 45	1.4102	25	0.9539	0.994 72	0.9488	40	0.7014	0.989 81	0.6942
15	1.2257	0.996 81	1.2218	30	0.8542	0.993 21	0.8484	45	0.6425	0.987 73	0.6346
20	1.0755	0.995 84	1.0710	35	0.7711	0.991 72	0.7647	50	0.5920	0.985 44	0.5834
$x_2 = 3.606 \times 10^{-3}$											
10	1.4365	0.997 14	1.4324	25	0.9649	0.994 38	0.9595	40	0.7057	0.989 38	0.6982
15	1.2435	0.996 47	1.2391	30	0.8628	0.992 90	0.8567	45	0.6459	0.987 31	0.6377
20	1.0895	0.995 48	1.0846	35	0.7763	0.991 18	0.7694	50	0.5951	0.985 06	0.5862

Table 3. Experimental Results of Kinematic Viscosity, Density, and Absolute Viscosity for Water (1) + 2-Methyl-2-Butanol (2)

t/°C	ν/mm^2·s^{-1}	ρ/g·cm^{-3}	η/mPa·s
$x_2 = 4.000 \times 10^{-4}$			
10	1.3230	0.999 40	1.3222
20	1.0157	0.997 93	1.0136
30	0.8131	0.995 35	0.8093
40	0.6717	0.992 01	0.6663
50	0.5694	0.987 72	0.5624
$x_2 = 1.200 \times 10^{-3}$			
10	1.3504	0.999 02	1.3491
20	1.0343	0.997 56	1.0318
30	0.8254	0.994 94	0.8212
40	0.6819	0.991 53	0.6761
50	0.5771	0.987 18	0.5697
$x_2 = 1.998 \times 10^{-3}$			
10	1.3870	0.998 49	1.3849
20	1.0589	0.997 03	1.0557
30	0.8456	0.994 40	0.8409
40	0.6951	0.991 00	0.6889
50	0.5880	0.986 62	0.5801
$x_2 = 2.800 \times 10^{-3}$			
10	1.4257	0.997 81	1.4226
20	1.0847	0.996 27	1.0807
30	0.8584	0.993 88	0.8532
40	0.7043	0.990 29	0.6975
50	0.5932	0.986 08	0.5849
$x_2 = 3.600 \times 10^{-3}$			
10	1.4646	0.997 39	1.4608
20	1.1070	0.995 84	1.1024
30	0.8751	0.993 24	0.8692
40	0.7166	0.989 71	0.7093
50	0.6036	0.985 48	0.5948

Results and Discussion

The experimental results of viscosity and density for the systems water + 1-pentanol and water + 2-methyl-2-butanol are given in Tables 2 and 3, respectively.

The viscosity data were correlated by the following two equations:

(1) Grunberg−Nissan (1949) equation

$$\ln \eta = x_1 \ln \eta_1 + x_2 \ln \eta_2 + x_1 x_2 \delta_{12} \tag{3}$$

where η is the absolute viscosity of the mixture, x_1 and x_2 are the mole fractions of components 1 and 2, η_1 and η_2 are the absolute viscosities of pure components 1 and 2, and δ_{12} is a parameter accounting for the nature of the substances in the mixture.

(2) Heric (1966) equation

$$\ln \nu = x_1 \ln (\nu_1 M_1) + x_2 \ln(\nu_2 M_2) - \ln(x_1 M_1 + x_2 M_2) + x_1 x_2[a_{12} + a'_{12}(x_1 - x_2)] \tag{4}$$

where ν is the kinematic viscosity of the mixture, ν_1 and ν_2 are the kinematic viscosities of pure components 1 and 2, M_1 and M_2 are the molecular weights of components 1 and 2, and α_{12} and α'_{12} are adjustable parameters to account for the characteristics of the mixture.

The least-squares regression analysis was applied to correlate the experimental viscosities to determine the adjustable parameters δ_{12}, α_{12} and α'_{12} in eqs 3 and 4. The results of the correlation and standard deviations are given

Table 4. Correlated Results of the Adjustable Parameters and Standard Deviations, σ

	Grunberg−Nissan		Heric		
t/°C	δ_{12}	σ	α_{12}	α'_{12}	σ
			Water + 1-Pentanol		
10	26.598	0.0036	−245.22	−276.21	0.0036
15	24.487	0.0030	−259.65	−288.61	0.0030
20	22.558	0.0025	−277.59	−304.75	0.0024
25	20.974	0.0022	−326.83	−352.66	0.0020
30	19.661	0.0021	−441.83	−467.02	0.0017
35	18.201	0.0023	−617.51	−642.24	0.0016
40	17.207	0.0021	−685.75	−709.89	0.0014
45	16.211	0.0018	−613.58	−636.31	0.0014
50	15.381	0.0018	−597.23	−619.05	0.0014
			Water + 2-Methyl-2-Butanol		
10	32.609	0.0058	−420.59	−458.68	0.0062
20	27.984	0.0042	−601.66	−636.19	0.0038
30	24.405	0.0040	−853.25	−885.68	0.0032
40	21.796	0.0034	−952.65	−983.07	0.0024
50	19.644	0.0030	−962.26	−990.60	0.0023

in Table 4. The agreement between the experimental and calculated viscosities is very good.

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