J. Chem. Eng. Data **1997,** *42,* 854−857

Density and Viscosity for Monoethanolamine + 1-Propanol, + 1-Hexanol, and + 1-Octanol

Ming-Jer Lee,* Ting-Kuei Lin, Yung-Hsiang Pai, and Kuo-Sheng Lin

Department of Chemical Engineering, National Taiwan Institute of Technology, Taipei 106, Taiwan

Densities and viscosities were measured for monoethanolamine (MEA) + 1-propanol, MEA + 1-hexanol, and MEA + 1-octanol at 303.15 K, 313.15 K, and 323.15 K. The excess volumes and viscosity deviations from the mole fraction average were calculated and correlated by a Redlich−Kister type equation. McAllister's three-body interaction model was also applied to correlate the kinematic viscosities.

Introduction

Monoethanolamine (MEA) is a feasible agent for removing carbon dioxide and hydrogen sulfide from sour gases. The volumetric and transport properties of the related fluids and mixtures are of importance to design the removal process. The present work is a part of systematic studies on densities and viscosities for binary solutions containing MEA and a polar cosolvent. Lee and Lin (1995) reported previously the densities and viscosities of MEA + water, + ethanol, and + 2-propanol at temperatures from 303.15 K to 323.15 K and at atmospheric pressure. This work extends the uncommon constituents to heavier 1-alkanols, including 1-propanol, 1-hexanol, and 1-octanol. The investigated conditions are also in the temperature range of 303.15 K to 323.15 K and at atmospheric pressure (nominal value = 0.1 MPa). No data are available in the literature for those mixtures at comparable conditions.

Experimental Section

Monoethanolamine (99 mass %) was purchased from Janssen Chimica, 1-propanol (99.5 mass %) from Ferak Chemical Co., 1-hexanol (99 mass %) from Fluka Chemical Co., and 1-octanol (99+ mass %) from Aldrich Chemical Co. The purity of the chemicals was checked by gas chromatography analysis and by determining their densities at specific temperatures. No impurity peak was detected for MEA, 1-propanol, and 1-octanol. The impurity in 1-hexanol is about 0.4%. All these compounds were used without further purification.

Pycnometers and a HAAKE falling-ball viscometer were employed to measure density and viscosity, respectively. To prevent the viscometer from being corroded by MEA, the metal surfaces in contact with the sample were gold plated. The detailed experimental procedure has been described elsewhere (Lee and Wei, 1992). In viscosity measurements, the falling time (t) was converted into viscosity (η) by:

$$\eta = K(\rho_b - \rho)t \qquad (1)$$

where ρ is the density of the liquid determined at the measuring temperature and ρ_b (=2.217 g cm^{-3}) is the density of the boron silica glass ball. The ball constant K was calibrated with literature viscosity data. Subsequently the ball constant was correlated by a linear function in terms of liquid density over a density range of 0.7632 g cm^{-3} to 1.002 g cm^{-3}. The calibration results were detailed elsewhere (Lee and Lin, 1995). In general, the accuracy of measurements is estimated to be ±0.1% for density, ±1.5% for viscosity, ±0.1 K for temperature, and ±0.0004 in mole fraction for mixture preparation.

Table 1. Comparison of Density and Viscosity of Pure Components from This Work with the Literature Values

		ρ/g·cm^{-3}		η/mPa·s	
compd	T/K	this work	lit.	this work	lit.
MEA	303.15	1.009	1.00889^a 1.008^b	15.0	15.1^b
	313.15	0.9999	1.00020^a 1.000^b	9.94	10.0^b
	323.15	0.9918	0.99179^a 0.9924^b	6.87	6.97^b
1-propanol	303.15	0.7956	0.7957^{c,d}	1.72	1.734^i
	313.15	0.7873	0.7875^{c,d}	1.39	1.389^i
	323.15	0.7786	0.7790^{c,d}	1.12	1.130^i
1-hexanol	303.15	0.8120	0.81198^e 0.8121^c 0.8127^f	3.84	3.90^j
	313.15	0.8046	0.8046^c 0.8054^f	2.90	2.89^j
	323.15	0.7972	0.79686^g 0.7970^c 0.7979^f	2.23	2.21^j
1-octanol	303.15	0.8181	0.8184^c 0.8188^h	6.24	6.298^k
	313.15	0.8112	0.8108^c 0.8117^h	4.53	4.577^k
	323.15	0.8038	0.8031^c 0.8044^h	3.37	3.428^k

[a] Murrieta-Guevara and Trejo Rodriguez (1984). [b] Diguillo et al. (1992). [c] TRC Thermodynamic Tables (d-5000, 1994). [d] TRC Thermodynamic Tables (d-5030, 1994). [e] Naidu and Naidu (1981). [f] TRC Thermodynamic Tables (d-5090, 1994). [g] Heintz et al. (1986). [h] TRC Thermodynamic Tables (d-5110, 1994). [i] Sollman and Marschall (1990). [j] Matsuo and Makita (1989). [k] Singh et al. (1990).

Results and Discussion

Table 1 compares the measured density (ρ) and viscosity (η) data with the literature values for the pure compounds. The agreement is about within the uncertainty of the measurements. The experimental results of MEA + 1-propanol, MEA + 1-hexanol and MEA + 1-octanol are listed in Tables 2−4, respectively. Figure 1 illustrates the kinematic viscosities ($\nu = \eta/\rho$) of these three binary solutions varying with the mole fraction of MEA (x_1) at 313.15 K, indicating that the kinematic viscosities increase monotonically with the composition of MEA.

The excess volume (V^E) was calculated from the density data by

---

* To whom correspondence should be addressed. Fax: 886-2-737-6644. E-mail: mjl@ch.ntit.edu.tw.

S0021-9568(97)00063-0 CCC: $14.00

Table 2. Density (ρ), Viscosity (η), and Kinematic Viscosity (ν) for MEA (1) + 1-Propanol (2)

	303.15 K			313.15 K			323.15 K		
x_1	ρ/g·cm^{-3}	η/mPa·s	ν/10^{-6} m^2 s^{-1}	ρ/g·cm^{-3}	η/mPa·s	ν/10^{-6} m^2 s^{-1}	ρ/g·cm^{-3}	η/mPa·s	ν/10^{-6} m^2 s^{-1}
0.0998	0.8145	2.09	2.57	0.8059	1.66	2.06	0.7977	1.35	1.69
0.1999	0.8346	2.56	3.07	0.8262	2.00	2.42	0.8197	1.59	1.94
0.3005	0.8547	3.17	3.71	0.8463	2.42	2.86	0.8380	1.92	2.29
0.4000	0.8754	3.97	4.54	0.8669	2.97	3.43	0.8585	2.30	2.68
0.5000	0.8966	4.94	5.51	0.8883	3.63	4.09	0.8797	2.75	3.13
0.6000	0.9182	6.22	6.77	0.9100	4.44	4.88	0.9015	3.31	3.67
0.7000	0.9401	7.70	8.19	0.9317	5.41	5.81	0.9234	3.93	4.26
0.8000	0.9626	9.64	10.0	0.9544	6.62	6.94	0.9459	4.73	5.00
0.9000	0.9856	12.0	12.2	0.9774	8.11	8.30	0.9689	5.69	5.87

Table 3. Density (ρ), Viscosity (η), and Kinematic Viscosity (ν) for MEA (1) + 1-Hexanol (2)

	303.15 K			313.15 K			323.15 K		
x_1	ρ/g·cm^{-3}	η/mPa·s	ν/10^{-6} m^2 s^{-1}	ρ/g·cm^{-3}	η/mPa·s	ν/10^{-6} m^2 s^{-1}	ρ/g·cm^{-3}	η/mPa·s	ν/10^{-6}m^2 s^{-1}
0.1000	0.8220	4.07	4.95	0.8145	3.08	3.78	0.8069	2.37	2.94
0.2000	0.8331	4.48	5.38	0.8254	3.34	4.05	0.8178	2.57	3.14
0.3000	0.8456	5.04	5.96	0.8378	3.72	4.44	0.8303	2.84	3.42
0.4000	0.8597	5.68	6.61	0.8518	4.15	4.87	0.8443	3.13	3.71
0.5000	0.8758	6.54	7.47	0.8678	4.70	5.42	0.8602	3.51	4.08
0.6000	0.8943	7.62	8.52	0.8863	5.41	6.10	0.8786	3.98	4.53
0.7000	0.9158	8.84	9.65	0.9078	6.17	6.80	0.9000	4.49	4.99
0.8000	0.9409	10.4	11.1	0.9330	7.18	7.70	0.9251	5.16	5.58
0.9000	0.9713	12.3	12.7	0.9632	8.31	8.63	0.9552	5.88	6.16

Table 4. Density (ρ), Viscosity (η), and Kinematic Viscosity (ν) for MEA (1) + 1-Octanol (2)

	303.15 K			313.15 K			323.15 K		
x_1	ρ/g·cm^{-3}	η/mPa·s	ν/10^{-6} m^2 s^{-1}	ρ/g·cm^{-3}	η/mPa·s	ν/10^{-6} m^2 s^{-1}	ρ/g·cm^{-3}	η/mPa·s	ν/10^{-6} m^2 s^{-1}
0.1000	0.8257	6.48	7.85	0.8185	4.68	5.72	0.8110	3.49	4.30
0.2000	0.8342	6.80	8.15	0.8269	4.93	5.96	0.8194	3.68	4.49
0.3000	0.8442	7.36	8.72	0.8368	5.28	6.31	0.8292	3.92	4.73
0.4000	0.8560	8.14	9.51	0.8483	5.77	6.80	0.8405	4.23	5.03
0.5000	0.8697	9.01	10.4	0.8619	6.27	7.27	0.8542	4.55	5.33
0.6000	0.8861	9.97	11.3	0.8782	6.83	7.78	0.8704	4.90	5.63
0.7000	0.9064	11.0	12.1	0.8983	7.48	8.33	0.8904	5.34	6.00
0.8000	0.9317	12.1	13.0	0.9236	8.16	8.83	0.9156	5.79	6.32
0.9000	0.9649	13.4	13.9	0.9562	8.98	9.39	0.9479	6.29	6.64

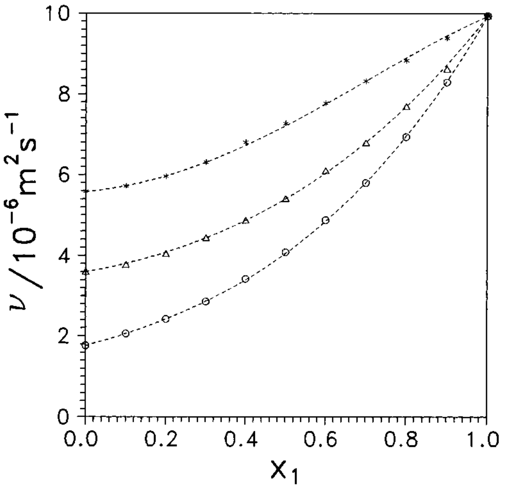

Figure 1. Kinematic viscosities at 313.15 K: (○) MEA (1) + 1-propanol (2); (△) MEA (1) + 1-hexanol (2); (*) MEA (1) + 1-octanol (2); (---) calculated from McAllister's three-body model.

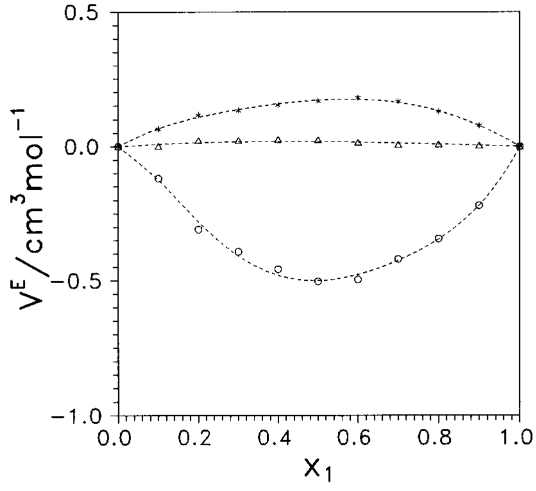

Figure 2. Excess volumes at 313.15 K: (○) MEA (1) + 1-propanol (2); (△) MEA (1) + 1-hexanol (2); (*) MEA (1) + 1-octanol (2); (---) calculated from eq 5.

$$V^E = V - (x_1V_1 + x_2V_2) \qquad (2)$$

with

$$V = (x_1M_1 + x_2M_2)/\rho \qquad (3)$$

where V is the molar volume of mixture and V_1, M_1, V_2, and M_2 are molar volumes and molecular weights of the components 1 and 2, respectively. Figure 2 presents the excess volumes at 313.15 K for the investigated systems. It shows that the excess volumes change from negative to positive with increasing molecular size of 1-alkanols; that is, volume contraction occurs in MEA + 1-propanol and volume expansion occurs in MEA + 1-octanol. The volume changes of mixing are very small ($|V^E| < 0.06$ cm^3·mol^{-1}) for MEA + 1-hexanol over the entire composition range.

The viscosity deviation from a mole fraction average ($\delta\eta$) is given by

$$\delta\eta = \eta - (x_1\eta_1 + x_2\eta_2) \qquad (4)$$

Table 5. Correlated Results for Excess Volumes

mixture	T/K	A_0	A_1	A_2	A_3	AAD[a]/cm^3 mol^{-1}
MEA + 1-propanol	303.15	−1.8662	0.0844	0.1836	−0.4899	0.006
	313.15	−1.9985	0.0758	0.1335	−1.1405	0.011
	323.15	−2.0714	0.1105	−0.0638	−0.5230	0.009
MEA + 1-hexanol	303.15	0.0950	0.1204			0.009
	313.15	0.0746	−0.0291			0.005
	323.15	0.0976	−0.1336			0.008
MEA + 1-octanol	303.15	0.5361	0.3137	−0.0301	−0.1349	0.010
	313.15	0.6879	0.1765	0.1845	−0.1588	0.004
	323.15	0.7423	0.1109	0.3824	0.0909	0.006

[a] AAD = $(1/n)\ \sum_{k=1}^{n} |V^{E}_{k,\mathrm{calc}} - V^{E}_{k,\mathrm{expt}}|$.

Table 6. Correlated Results for Viscosity Deviations ($\delta\eta$)

mixture	T/K	B_0	B_1	B_2	B_3	AAD[a]/mPa·s
MEA + 1-propanol	303.15	−13.6166	−4.3526	−1.5303	−0.9366	0.01
	313.15	−8.1643	−2.5198	−0.8062	−0.3115	0.01
	323.15	−4.9853	−1.5357	−0.5055	−0.4051	0.01
MEA + 1-hexanol	303.15	−11.3311	−3.3050	−3.5153	−2.3751	0.02
	313.15	−6.7379	−1.5603	−1.9020	−1.8441	0.02
	323.15	−4.0842	−0.8814	−0.8873	−0.7636	0.01
MEA + 1-octanol	303.15	−6.5761	1.2167	−1.7658	−2.8365	0.02
	313.15	−3.8899	0.1435	−1.0166	−0.5323	0.01
	323.15	−2.2784	0.0484	−0.4123	−0.0579	0.06

[a] AAD = $(1/n)\ \sum_{k=1}^{n} |\delta\eta_{k,\mathrm{calc}} - \delta\eta_{k,\mathrm{expt}}|$.

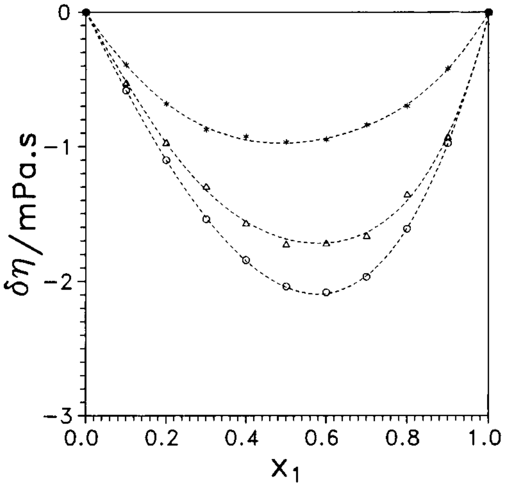

Figure 3. Viscosity deviations at 313.15 K: (○) MEA (1) + 1-propanol (2); (△) MEA (1) + 1-hexanol (2); (*) MEA (1) + 1-octanol (2); (---) calculated from eq 6.

where η_i is the viscosity of pure component i. The viscosity deviations at 313.15 K varying with the mole fraction of MEA are illustrated in Figure 3. Negative deviations are exhibited for those three binary systems. It is found that the negative values of viscosity deviations increase with decreasing chain length of 1-alkanols.

The isothermal excess volumes and viscosity deviations were correlated respectively by a Redlich−Kister type equation:

$$V^{E}/(\mathrm{cm^3{\cdot}mol^{-1}}) = x_1x_2 \sum_{k=0}^{3} A_k(x_1 - x_2)^k \tag{5}$$

$$\delta\eta/(\mathrm{mPa{\cdot}s}) = x_1x_2 \sum_{k=0}^{3} B_k(x_1 - x_2)^k \tag{6}$$

The coefficients of A_k and B_k were obtained by fitting the equations to the experimental values with a least-squares algorithm. Tables 5 and 6 give the results. The Redlich−Kister type equation correlates the excess volumes and viscosity deviations very well.

Table 7. Correlated Results of McAllister's Three-Body Model

mixture	T/K	ν_{12}	ν_{21}	$10^2 \times$ AAD[a]
MEA + 1-propanol	303.15	7.7963	3.7704	0.35
	313.15	5.5226	2.9170	0.32
	323.15	3.9747	2.4411	0.33
MEA + 1-hexanol	303.15	9.2899	5.6464	0.64
	313.15	6.5887	4.2637	0.48
	323.15	4.9492	3.2886	0.35
MEA + 1-octanol	303.15	13.3199	8.2172	0.66
	313.15	9.0534	5.9875	0.43
	323.15	6.4897	4.5839	0.21

[a] AAD = $(1/n)\ \sum_{k=1}^{n} |\nu_{k,\mathrm{calc}} - \nu_{k,\mathrm{expt}}|/\nu_{k,\mathrm{expt}}$.

McAllister's multibody interaction model (McAllister, 1960) is widely used for correlating the kinematic viscosity of liquid mixtures. The three-body model was defined as

$$\ln \nu = x_1^{3} \ln \nu_1 + 3x_1^{2}x_2 \ln \nu_{12} + 3x_1x_2^{2} \ln \nu_{21} + x_2^{3} \ln \nu_2 - \ln[x_1 + x_2(M_2/M_1)] + 3x_1^{2}x_2 \ln[(2 + M_2/M_1)/3] + 3x_1x_2^{2} \ln[(1 + 2M_2/M_1)/3] + x_2^{3} \ln(M_2/M_1) \tag{7}$$

Table 7 reports the correlated results. It reveals that the three-body model is adequate enough for those investigated systems.

Literature Cited

Diguillo, R. M.; Lee, R. J.; Schaeffer, S. T.; Brasher, L. L.; Teja, A. S. Densities and Viscosities of the Ethanolamines. *J. Chem. Eng. Data* **1992**, *37*, 239−242.

Heintz, A.; Schmittecker, B.; Wanger, D.; Lichtenthaler, R. N. Excess Volumes of Binary 1-Alkanol/Hexane Mixtures at Temperatures between 283.15 and 323.15 K. *J. Chem. Eng. Data* **1986**, *31*, 487−492.

Lee, M. J.; Wei, M. C. Densities and Viscosities of 2-Butanone/Dibutyl Ether, 2-Picoline/2-Butanone, and 2-Picoline/Water Mixtures. *J. Chem. Eng. Data* **1992**, *37*, 209−212.

Lee, M. J.; Lin, T. K. Densities and Viscosities for Monoethanolamine + Water, + Ethanol, and + 2-Propanol. *J. Chem. Eng. Data* **1995**, *40*, 336−339.

McAllister, R. A. The Viscosity of Liquid Mixtures. *AIChE J.* **1960**, *6*, 427−431.

Matsuo, S.; Makita, T. Viscosities of Six 1-Alkanols at Temperatures in the Range 298−348 K and Pressures up to 200 MPa. *Int. J. Thermophys.* **1989**, *10*, 833−843.

Murrieta-Guevara, F.; Trejo Rodriguez, A. Liquid Density as a Function of Temperature of Five Organic Solvents. *J. Chem. Eng. Data* **1984**, *29*, 204−206.

Naidu, G. R.; Naidu, P. R. Excess Volumes of Ternary Mixtures Containing Methyl Ethyl Ketone, 1-Alkanols, and an Alkane. *J. Chem. Eng. Data* **1981**, *26*, 197−200.

Singh, R. P.; Sinha, C. P.; Das, J. C.; Ghosh, P. Viscosity and Density of Ternary Mixtures of Toluene, Bromobenzene, 1-Hexanol, and 1-Octanol. *J. Chem. Eng. Data* **1990**, *35*, 93−97.

Sollman, K.; Marschall, E. Viscosity of Selected Binary, Ternary, and Quaternary Liquid Mixtures. *J. Chem. Eng. Data* **1990**, *35*, 375−381.

TRC Thermodynamic Tables—Non-Hydrocarbons; Thermodynamic Research Center, The Texas A&M University System: College Station, TX, 1994.

Received for review March 10, 1997. Accepted May 15, 1997.⊗

JE9700636

⊗ Abstract published in *Advance ACS Abstracts,* July 1, 1997.