Ternary ion interaction parameters for various mixture with common ion will be evaluated in a subsequent paper.

Literature Cited

(1) Pitzer, K. S. *J. Phys. Chem.* **1973**, *77*, 268.
(2) Pitzer, K. S., Mayorga, G. *J. Phys. Chem.* **1973**, *77*, 2300.
(3) Pitzer, K. S.; Mayorga, G. *J. Solution Chem.* **1974**, *3*, 539.
(4) Pitzer, K. S.; Kim, J. J. *J. Am. Chem. Soc.* **1974**, *96*, 5701.
(5) Harvie, C. E.; Weare, J. H. *Geochim. Cosmochim. Acta* **1980**, *44*, 981.
(6) Harvie, C. E.; Eugster, H. P.; Weare, J. H. *Geochim. Cosmochim. Acta* **1982**, *46*, 1603.
(7) Harvie, C. E.; Moller, N.; Weare, J. H. *Geochim. Cosmochim. Acta* **1984**, *48*, 723.
(8) Kelly, B.; Frederick, W. J., Jr. In *Application of Chemical Engineering Principle in the Forest Products and Related Industries*; Kayihan, F., Krieger-Brackett, B., Ed.; AIChE Forest Products Division: Seattle, WA, 1986.
(9) Chen, C. C.; Britt, H. I.; Boston, J. F.; Evans, L. B. *AIChE J.* **1979**, *25*, 820.
(10) Whitfield, M. *Mar. Chem.* **1975**, *3*, 197.
(11) Whitfield, M. *Geochim. Cosmochim. Acta* **1975**, *39*, 1545.
(12) Hamer, W. J.; Wu, Y. C. *J. Phys. Chem. Ref. Data* **1972**, *1*, 1047.
(13) Goldberg, R. N. *J. Phys. Chem. Ref. Data* **1981**, *10*, 671.
(14) Goldberg, R. N.; Nuttall, R. L. *J. Phys. Chem. Ref. Data* **1978**, *7*, 263.
(15) Goldberg, R. N.; Nuttall, R. L.; Staples, B. R. *J. Phys. Ref. Data* **1979**, *8*, 923.
(16) Goldberg, R. N. *J. Phys. Chem. Ref. Data* **1979**, *8*, 1005.
(17) Goldberg, R. N. *J. Phys. Chem. Ref. Data* **1981**, *10*, 1.
(18) Spedding, F. H.; Weber, H. O.; Saeger, V. W.; Petheram, H. H.; Rard, J. A.; Habenschuss, A. *J. Chem. Eng. Data* **1976**, *21*, 341.
(19) Rard, J. A.; Weber, H. O.; Spedding, F. H. *J. Chem. Eng. Data* **1977**, *22*, 187.
(20) Rard, J. A.; Shiers, L. E.; Heiser, D. J.; Spedding, F. H. *J. Chem. Eng. Data* **1977**, *22*, 337.
(21) Rard, J. A.; Miller, D. G. *J. Chem. Eng. Data* **1979**, *24*, 348.
(22) Robinson, R. A.; Stokes, R. H. *Electrolyte Solutions*, 2nd ed.; Butterworths: London, 1959.
(23) Pitzer, K. S. *J. Chem. Soc., Faraday Trans. 2* **1972**, *68*, 101.
(24) Pitzer, K. S., Peterson, J. R.; Silvester, L. F. *J. Solution Chem.* **1978**, *7*, 45.
(25) Staples, B. R. *J. Phys. Ref. Data* **1981**, *10*, 765.
(26) Bonner, O. D. *J. Chem. Eng. Data* **1979**, *24*, 210.
(27) Platford, R. A. *Can. J. Chem.* **1969**, *47*, 2271.
(28) Bonner, O. D. *J. Chem. Eng. Data* **1976**, *21*, 498.
(29) Kalman, E.; Schwabe, K. *J. Solution Chem.* **1979**, *8*, 1.
(30) Bonner, O. D. *J. Chem. Eng. Data* **1982**, *27*, 62.
(31) Macaskill, J. B.; Robinson, R. A.; Bates, R. G. *J. Chem. Eng. Data* **1977**, *22*, 411.
(32) Staples, B. R. *J. Phys. Chem. Ref. Data* **1981**, *10*, 779.
(33) Libus, Z.; Sadowska, T.; Trzaskowski, J. *J. Chem. Thermodyn.* **1979**, *11*, 1151.
(34) Libus, Z.; Zak, E.; Sadowaska, T. *J. Chem. Thermodyn.* **1984**, *16*, 257.
(35) Kangro, W.; Groeneveld, A. *Z. Phys. Chem. (Frankfurt am Main)* **1962**, *32*, 110.
(36) Wynveen, R. A.; Dye, J. L.; Brubaker, C. H., Jr. *J. Am. Chem. Soc.* **1960**, *82*, 4441.
(37) Bonner, O. D. *J. Chem. Thermodn.* **1979**, *11*, 559.
(38) Groves, K. O.; Dye, J. L. Brubaker, C. H., Jr. *J. Am. Chem. Soc.* **1960**, *82*, 4445.
(39) Bonner, O. D. *J. Chem. Thermodyn.* **1979**, *11*, 563.
(40) Rard, J. A.; Miller, D. G. *J. Chem. Eng. Data* **1981**, *26*, 33.
(41) Wu, Y. C.; Hamer, W. J. *J. Phys. Chem. Ref. Data* **1980**, *9*, 513.

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Densities and Viscosities of Binary Liquid Mixtures Containing Bromoform at 45 °C

Lata S. Manjeshwar and Tejraj M. Aminabhavi*

Department of Chemistry, Karnatak University, Dharwad, India 580 003

Densities and viscosities of eight binary liquid mixtures of bromoform with carbon tetrachloride, dimethyl sulfoxide, cyclohexane, bromobenzene, dimethylformamide, methyl ethyl ketone, ethyl acetate, and methanol are presented at 45 °C as a function of composition of the mixtures. A theoretical correlation is attempted with McAllister, Heric, and Auslander viscosity models.

Introduction

In the course of our studies on the thermodynamic properties of binary mixtures, we have reported at 25 °C excess volumes (*1*) and viscosities (*2*) for binary mixtures of bromoform with carbon tetrachloride, dimethyl sulfoxide, cyclohexane, bromobenzene, dimethylformamide, methyl ethyl ketone, ethyl acetate, and methanol. As an extension of that work, we have now measured the densities and viscosities for the same eight systems at 45 °C.

Experimental Section

All the chemicals used were of reagent grade. They were distilled by fractionating through a 2-ft column. Only bromoform (Merck) was used directly without further purification since it was available in the highest commercial purity. Purity of the solvents was ascertained by the constancy of their boiling points during final distillations. Due to the nonavailability of direct experimental data at 45 °C for most of the solvents used here, the boiling points, viscosities, and refractive indices of the pure components at 25 °C were checked against the literature values (see Table I) to ascertain their purities (*4*).

Table I. Some Physical Properties of the Liquids Studied

	boiling point, °C		viscosity, kg/(m/s)		refractive index[a]	
component	measd	lit. (*4*)	measd	lit. (*4*)	measd	lit. (*4*)
bromoform	149.00	149.50	0.1873	0.1890	1.5950	1.5956
carbon tetrachloride	76.20	76.75	0.0892	0.0902	1.4571	1.4574
dimethyl sulfoxide	190.00	189.85	0.2024	0.2021	1.4777	1.4773
cyclohexane	80.10	80.74	0.0883	0.0886	1.4229	1.4235
bromobenzene	155.90	156.05	0.1081	0.1040	1.5580	1.5571
dimethylformamide	152.80	153.00	0.0805	0.0800	1.4278	1.4282
methyl ethyl ketone	79.00	79.60	0.0475	0.0480	1.3759	1.3764
ethyl acetate	77.10	77.26	0.0439	0.0424	1.3702	1.3698
methanol	64.20	65.15	0.0590	0.0547	1.3258	1.3265

[a] Refractive index was measured with a Abbe refractometer.

Table II. Density and Viscosity Data for Binary Mixtures 45 °C

X_1	density, g/cm^3	viscosity $\times 10^{-1}$, kg/(m/s)	X_1	density, g/cm^3	viscosity $\times 10^{-1}$, kg/(m/s)
I. Bromoform (1)–Carbon Tetrachloride (2)					
0.0	1.561 31	0.744 85	0.6651	2.356 15	1.164 0
0.1597	1.745 45	0.821 50	0.8607	2.611 38	1.328 5
0.3179	1.932 34	0.913 11	1.0	2.782 32	1.476 40
0.5191	2.175 23	1.055 8			
II. Bromoform (1)–Dimethyl Sulfoxide (2)					
0.0	1.086 93	1.365 80	0.5441	2.108 15	1.982 00
0.1216	1.338 58	1.568 00	0.5955	2.190 30	1.982 50
0.2541	1.595 75	1.787 40	0.8193	2.533 66	1.716 10
0.4430	1.935 79	1.978 40	1.0	2.782 32	1.476 40
III. Bromoform (1)–Cyclohexane (2)					
0.0	0.762 49	0.633 77	0.6911	2.073 39	1.112 70
0.1748	1.061 27	0.723 62	0.8747	2.486 39	1.309 00
0.3427	1.368 45	0.820 05	1.0	2.782 32	1.476 40
0.5476	1.770 66	0.976 94			
IV. Bromoform (1)–Bromobenzene (2)					
0.0	1.476 39	0.853 55	0.6863	2.328 70	1.271 70
0.1693	1.671 23	0.950 44	0.8710	2.591 82	1.395 80
0.3354	1.870 48	1.051 10	1.0	2.782 32	1.476 40
0.5411	2.131 48	1.176 80			
V. Bromoform (1)–Dimethylformamide (2)					
0.0	0.934 68	0.634 84	0.6142	2.133 94	1.471 10
0.1317	1.211 87	0.819 00	0.7204	2.322 70	1.518 00
0.2705	1.490 88	1.046 40	0.8296	2.505 72	1.518 60
0.4636	1.861 02	1.313 20	1.0	2.782 32	1.476 40
VI. Bromoform (1)–Methyl Ethyl Ketone (2)					
0.0	0.787 81	0.341 67	0.6499	2.095 85	1.037 80
0.1474	1.086 13	0.467 77	0.8502	2.493 09	1.298 40
0.3005	1.396 04	0.622 83	1.0	2.782 32	1.476 40
0.5019	1.800 69	0.852 26			
VII. Bromoform (1)–Ethyl Acetate (2)					
0.0	0.879 11	0.382 92	0.7671	2.312 83	1.179 30
0.2695	1.361 01	0.600 53	1.0	2.782 32	1.476 40
0.5228	1.835 83	0.877 89			
VIII. Bromoform (1)–Methanol (2)					
0.0	0.775 90	0.434 53	0.7234	2.501 71	1.260 50
0.1630	1.390 94	0.693 47	0.8987	2.696 97	1.383 30
0.3122	1.795 70	0.884 43	1.0	2.782 32	1.476 40
0.4563	2.095 90	1.043 40			

Solvent mixtures were prepared by weighing a calculated volume of each solvent in the mixture; special airtight glass-stoppered bottles were used for this purpose. Densities (ρ) and viscosities (η) at 45 °C were measured by the procedure described earlier (*3*). Triplicate measurements of each composition of the mixture showed a reproducibility range for density of ±0.000 06 g/cm^3 and for viscosity of ±0.000 04 kg/(m/s). However, only the average data are presented in Table II. The mole fractions (X_1) were calculated from the measured volumes and densities of individual components (*3*).

Results and Discussion

Experimental data of ρ and η are listed in Table II as a function of mole fraction (X_1) of the first component in the mixture (i.e., bromoform). To the best of our knowledge no data were available for the systems investigated here and hence no comparison with the published results was possible.

The binary kinematic viscosity (η/ρ) data have been correlated by using the cubic equation of McAllister (*5*) as well as the Heric (*6*) and Auslander (*7*) relations. Statistical analysis of the back-calculated values of viscosities in comparison to the measured values indicated an average percent deviation from 1.0 to 1.5 for McAllister equation; for the Auslander or Heric relations, this was found to be between 2.0 and 3.0.

Registry No. Bromoform, 75-25-2; carbon tetrachloride, 56-23-5; dimethyl sulfoxide, 67-68-5; cyclohexane, 110-82-7; bromobenzene, 108-86-1; dimethylformamide, 68-12-2; ethyl acetate, 141-78-6; ethyl methyl ketone, 78-93-3; methanol, 67-56-1.

Literature Cited

(1) Aminabhavi, T. M.; Manjeshwar, L. S.; Balundgi, R. H. *Indian J. Chem.* **1986**, *25A*, 465.
(2) Aminabhavi, T. M.; Manjeshwar, L. S.; Balundgi, R. H. *J. Chem. Eng. Data* **1987**, *32*, 50.
(3) Gokavi, G. S.; Raju, J. R.; Aminabhavi, T. M.; Balundgi, R. H.; Muddapur, M. V. *J. Chem. Eng. Data* **1986**, *31*, 15.
(4) Riddick, A. J.; Bunger, B. W. *Techniques of Organic Chemistry*, 3rd ed.; Wiley-Interscience: New York, 1970; Vol. II.
(5) McAllister, R. A. *AIChE J.* **1960**, *6*, 427.
(6) Heric, E. L. *J. Chem. Eng. Data* **1966**, *11*, 66.
(7) Auslander, G. *Br. Chem. Eng.* **1964**, *9*, 610.

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Experimental Densities and Derived Thermodynamic Properties for Carbon Dioxide–Water Mixtures

Mukund R. Patel and Philip T. Eubank*

Department of Chemical Engineering, Texas A&M University, College Station, Texas 77843

Vapor-phase densities have been measured for mixtures of 2, 5, 10, 25, and 50 mol % water in carbon dioxide by using a Burnett–isochoric apparatus. These experimental densities, which cover a temperature range from 323.15 to 498.15 K and a pressure range from 27 kPa to 10.34 MPa, are considered accurate to ±0.05%. Thermodynamic properties, derived from the experimental data for all five mixtures, have also been reported along with the corresponding pressure–enthalpy diagrams.

Introduction

Few high-accuracy density measurements are available for nonpolar/polar vapor mixtures over extended ranges of pressure, temperature, and composition. Such data are extremely important in developing reliable equations of state and in calculating thermodynamic properties.

Carbon dioxide–water mixtures have long been important in combustion studies and in the manufacture of carbonated beverages. Besides these well-known uses, they are de-

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