VISCOSITIES OF BINARY AND TERNARY AQUEOUS SOLUTIONS OF 2-AMINO-2-METHYLPROPAN-1-OL, 2-AMINO-2-METHYLPROPANE-1,3-DIOL, AND 2-AMINO-2-METHYLPROPAN-1-OL HYDROCHLORIDE

Francisco CHENLO[1,*], Ramón MOREIRA[2], Gerardo PEREIRA[3] and María-José VÁZQUEZ[4]

Department of Chemical Engineering, University of Santiago de Compostela, 15782 Santiago de Compostela, Spain; e-mail: [1] eqchenlo@usc.es, [2] eqmoncho@usc.es, [3] gepegon@usc.es, [4] eqmjvv@usc.es

Received October 26, 2001
Accepted January 16, 2002

Kinematic viscosities of aqueous solutions of 2-amino-2-methylpropan-1-ol (AMP), 2-amino-2-methylpropane-1,3-diol (AMPD), or 2-amino-2-methylpropan-1-ol hydrochloride (AMP-HCl) and aqueous ternary solutions (AMP and AMPD) and (AMP and AMP-HCl) were measured in the molality range from 0 to 2.5 mol kg^{-1} (0.5 mol kg^{-1} intervals) and temperatures from 293.1 to 323.1 K (5.0 K intervals). The viscosity data were correlated with concentration and temperature by empirical equations with deviations up to 1.4 and 3.3% for binary and ternary aqueous solutions, respectively.
Keywords: Viscosity; Amines; Amino alcohols; Absorption; Physical properties; Thermodynamics; Binary and ternary mixtures.

Absorption accompanied with chemical reaction in liquid phase is a method usually employed for the removal of CO_2 from gaseous streams of industrial origin or from polluted atmosphere. The main objective of these processes is to minimise the environmental pollution and, specifically, the greenhouse effect. In particular, aqueous solutions of several amines are used to intensify the absorption rate of the process relative to the physical absorption and to obtain enhancement factors greater than unity. These processes are carried out in aqueous single-solute[1,2] or two-solute solutions[3,4] or with sterically hindered amines[5,6], which leads to a considerable improvement of absorption rate and great savings of energy. Possibly, the presence of fine active carbon particles and one or several amines in aqueous suspension makes a system of considerable interest[7–11].

The design of industrial absorption columns and the application of absorption models require knowledge of parameters such as mass-transfer coefficients of corresponding physical and chemical absorption processes and

doi:10.1135/cccc20020293

the gas–liquid interfacial area, which are commonly obtained from laboratory experiments. In addition, to calculate these parameters, certain physical properties must be known, among them the viscosity, surface tension, or density of the liquid phase or the equilibrium gas–liquid relation. Sometimes the literature covers these needs but often few viscosity data have been reported in systematic studies with the concentration and temperature for the systems of interest in gas–liquid mass-transfer processes. The present paper reports measurements of kinematic viscosities of aqueous solutions of 2-amino-2-methylpropan-1-ol (AMP), 2-amino-2-methylpropane-1,3-diol (AMPD) and 2-amino-2-methylpropan-1-ol hydrochloride (AMP-HCl), and their combinations (AMP, AMPD) and (AMP, AMP-HCl) at various concentrations and temperatures of interest in mass-transfer processes. These viscosity data complement the data previously reported for monoethanolamine, diethanolamine, and 2-amino-2-methylpropan-1-ol aqueous solutions[12].

EXPERIMENTAL

Single-solute aqueous solutions of AMP, AMPD and AMP-HCl, and corresponding two-solute solutions were made up in concentrations ranging from 0 to 2.5 mol kg^{-1} for the former and 0 to 2.0 mol kg^{-1} for the latter (0.5 mol kg^{-1} intervals) and their viscosities were measured at temperatures ranging from 293.1 to 323.1 K (5.0 K intervals).

AMP (>96% pure), AMPD (>99% pure), and AMP-HCl (>99% pure) were Merck products. Water used as solvent was distilled and degassed. Solutions were made up by weighing the solutes and solvent on a Mettler AJ150 balance to within ±0.0001 g. Their concentrations are expressed as molalities (mol kg^{-1} solvent). Solutions were filtered before use.

The determination of kinematic data of solutions was based on the transit time of the liquid meniscus through a capillary, measured with an accuracy of ±0.01 s in a Schott-Geräte AVS 350 automatic Ubbelohde viscosimeter[13]. For each system, concentration and temperature, five measurements were performed and the values deviated by more than 0.2% from the mean value were discarded. The apparatus was calibrated with several solvents at different temperatures[14].

RESULTS AND DISCUSSION

Tables I–III list the experimental data of kinematic viscosities of the aqueous solutions of single solutes AMP (1), AMPD (2), and AMP-HCl (3), respectively, from 293.1 to 323.1 K and the concentration range 0–2.5 mol kg^{-1} for each solute. Tables IV and V list the kinematic viscosities of the two-solute solutions AMP + AMPD and AMP + AMP-HCl, respectively, in the concentration range 0–2.0 mol kg^{-1} for each solute. In all cases, the kinematic viscosity increases with increasing concentration. Moreover, the kinematic viscosity decreased with temperature.

TABLE I
Kinematic viscosity ($\nu \cdot 10^6$ ($m^2\ s^{-1}$)) for aqueous solutions of 2-amino-2-methylpropan-1-ol

T, K	m_1, mol kg^{-1}				
	0.50	1.00	1.50	2.00	2.50
293.1	1.193	1.426	1.699	1.987	2.352
298.1	1.051	1.247	1.474	1.686	1.986
303.1	0.933	1.102	1.293	1.447	1.697
308.1	0.841	0.980	1.135	1.281	1.481
313.1	0.761	0.885	1.017	1.133	1.299
318.1	0.691	0.796	0.912	1.026	1.157
323.1	0.630	0.717	0.820	0.928	1.033

TABLE II
Kinematic viscosity ($\nu \cdot 10^6$, $m^2\ s^{-1}$) for aqueous solutions of 2-amino-2-methylpropane-1,3-diol

T, K	m_2, mol kg^{-1}				
	0.50	1.00	1.50	2.00	2.50
293.1	1.198	1.377	1.654	1.933	2.212
298.1	1.058	1.214	1.440	1.678	1.909
303.1	0.943	1.077	1.268	1.469	1.655
308.1	0.849	0.962	1.126	1.297	1.454
313.1	0.769	0.867	1.009	1.157	1.288
318.1	0.699	0.787	0.913	1.054	1.149
323.1	0.642	0.716	0.827	0.938	1.035

The viscosity experimental data, ν ($m^2 s^{-1}$), for each single-solute aqueous solution were correlated with the molality *m* (mol kg^{-1}) and absolute temperature *T* (K). As a consequence, the kinematic viscosity was expressed by the empirical equation

$$\nu_i = \nu_{H_2O} + A m_i^B \exp(C / T^D) \qquad (1)$$

and for two-solute solutions the equation employed is

$$\nu_{i+j} = \nu_i + \nu_j - \nu_{H_2O} + E m_i m_j \exp(F / T^D) , \qquad (2)$$

where ν_{H_2O} is the kinematic viscosity of water obtained from literature[14]

$$\nu_{H_2O} = 9.5817 \cdot 10^{-8} \exp(5.9139 \cdot 10^7 / T^3) , \qquad (3)$$

TABLE III
Kinematic viscosity (ν · 10^6, $m^2 s^{-1}$) for aqueous solutions of 2-amino-2-methylpropan-1-ol hydrochloride

T, K	m_3, mol kg^{-1}				
	0.50	1.00	1.50	2.00	2.50
293.1	1.191	1.370	1.582	1.818	2.065
298.1	1.061	1.211	1.386	1.591	1.801
303.1	0.946	1.076	1.230	1.404	1.584
308.1	0.853	0.966	1.100	1.250	1.403
313.1	0.775	0.875	0.993	1.126	1.259
318.1	0.708	0.795	0.903	1.018	1.136
323.1	0.651	0.728	0.826	0.926	1.035

TABLE IV
Kinematic viscosity ($\nu \cdot 10^6$, $m^2\ s^{-1}$) for aqueous solutions of 2-amino-2-methylpropan-1-ol (1) and 2-amino-2-methylpropane-1,3-diol (2)

T, K	m_2, mol kg^{-1}			
	0.50	1.00	1.50	2.00
		m_1 = 0.50 mol kg^{-1}		
293.1	1.401	1.682	1.970	2.238
298.1	1.234	1.465	1.696	1.921
303.1	1.088	1.288	1.482	1.667
308.1	0.969	1.138	1.306	1.456
313.1	0.873	1.024	1.180	1.289
318.1	0.788	0.920	1.068	1.152
323.1	0.721	0.836	0.941	1.035
		m_1 = 1.00 mol kg^{-1}		
293.1	1.664	1.995	2.317	2.696
298.1	1.488	1.720	1.988	2.304
303.1	1.264	1.498	1.717	1.980
308.1	1.121	1.322	1.499	1.710
313.1	1.002	1.171	1.328	1.503
318.1	0.901	1.047	1.181	1.336
323.1	0.818	0.945	1.062	1.210
		m_1 = 1.50 mol kg^{-1}		
293.1	1.971	2.353	2.706	3.154
298.1	1.694	2.045	2.311	2.653
303.1	1.469	1.767	1.983	2.257
308.1	1.288	1.535	1.729	1.942
313.1	1.142	1.359	1.505	1.694
318.1	1.022	1.201	1.335	1.493
323.1	0.922	1.078	1.186	1.328
		m_1 = 2.00 mol kg^{-1}		
293.1	2.360	2.692	3.161	3.576
298.1	2.018	2.271	2.675	3.048
303.1	1.734	1.938	2.264	2.574
308.1	1.512	1.685	1.946	2.203
313.1	1.329	1.488	1.698	1.911
318.1	1.181	1.316	1.491	1.670
323.1	1.058	1.174	1.320	1.477

TABLE V
Kinematic viscosity ($\nu \cdot 10^6$, m^2 s^{-1}) for aqueous solutions of 2-amino-2-methylpropan-1-ol (1) and 2-amino-2-methylpropan-1-ol hydrochloride (3)

T, K	m_3, mol kg^{-1}			
	0.50	1.00	1.50	2.00
		m_1 = 0.50 mol kg^{-1}		
293.1	1.423	1.634	1.876	2.172
298.1	1.250	1.423	1.633	1.846
303.1	1.105	1.253	1.437	1.617
308.1	0.991	1.119	1.272	1.429
313.1	0.892	1.006	1.141	1.278
318.1	0.806	0.913	1.030	1.150
323.1	0.735	0.829	0.937	1.042
		m_1 = 1.00 mol kg^{-1}		
293.1	1.701	1.933	2.207	2.510
298.1	1.480	1.673	1.906	2.157
303.1	1.285	1.461	1.659	1.871
308.1	1.141	1.295	1.459	1.639
313.1	1.020	1.156	1.298	1.466
318.1	0.919	1.041	1.165	1.304
323.1	0.835	0.944	1.053	1.180
		m_1 = 1.50 mol kg^{-1}		
293.1	1.991	2.280	2.586	2.921
298.1	1.715	1.956	2.209	2.487
303.1	1.491	1.693	1.908	2.139
308.1	1.312	1.488	1.665	1.862
313.1	1.168	1.318	1.472	1.639
318.1	1.046	1.183	1.313	1.459
323.1	0.944	1.059	1.174	1.312
		m_1 = 2.00 mol kg^{-1}		
293.1	2.340	2.664	3.017	3.384
298.1	2.000	2.262	2.562	2.872
303.1	1.722	1.941	2.188	2.445
308.1	1.499	1.686	1.887	2.103
313.1	1.327	1.487	1.659	1.842
318.1	1.182	1.320	1.468	1.638
323.1	1.061	1.179	1.310	1.458

the parameter D has been obtained by optimisation for systems of one or two solutes as 3 and 2, respectively, and A, B, C, E and F are different parameters optimised by calculation. Equation (*2*) leads to the values of kinematic viscosities of aqueous two-solute solutions as function of the respective values of aqueous solutions of single solute.

Table VI presents numerical values obtained for parameters A, B, and C from single-solute aqueous solutions after application of Eqs (*1*) and (*3*) to overall experimental data. Maximum deviations obtained relative to experimental data were 1.25, 1.4, and 1.3% for systems AMP, AMPD, and AMP-HCl, respectively. The continuous lines drawn in Fig. 1, where experimental data are also shown, provide correlations to AMPD aqueous solutions, as example. AMP and AMP-HCl aqueous solutions, similar behaviour was observed. Table VI also gives numerical values of parameters E and F after applying Eqs (*2*) and (*3*) to the experimental data of kinematic viscosities for two-solute aqueous solutions. The maximum deviations obtained were 3.1 and 3.3% for systems AMP + AMPD and AMP + AMP-HCl, respectively. The continuous lines drawn in Fig. 2, where experimental data are also shown, provide correlation related to AMP + AMP-HCl aqueous solutions. AMP + AMPD, similar behaviour was observed.

In all cases, the mentioned behaviour of kinematic viscosity with temperature and solute concentration is observed. Furthermore, the proposed correlation is satisfactory in all ranges of concentration and temperature examined both in single-solute and two-solute aqueous solutions.

TABLE VI
Parameters (A, B, C, E, and F) of Eqs (*1*) and (*2*) for single-solute and two-solute aqueous solutions

System	$A \cdot 10^8$ $m^2\ s^{-1}\ (mol\ kg)^{-B}$	B	$C \cdot 10^{-7}$ K^{-3}	$E \cdot 10^{10}$ $m^2\ s^{-1}\ (mol\ kg)^{-2}$	$F \cdot 10^{-5}$ K^{-2}
AMP	1.0030	1.1859	9.4333		
AMPD	1.3543	1.1671	8.5466		
AMP-HCl	2.0112	1.0878	7.3905		
AMP + AMPD				1.4306	6.0505
AMP + AMP-HCl				1.3533	6.0137

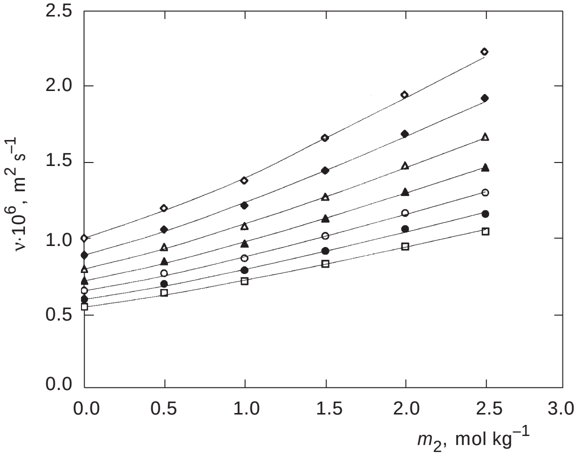

FIG. 1

Kinematic viscosity, ν, of aqueous solutions of AMPD as function of molality m_2 and temperatures T (K): ✧ 293.1, ◆ 298.1, Δ 303.1, ▲ 308.1, ❍ 313.1, ● 318.1, ❏ 323.1

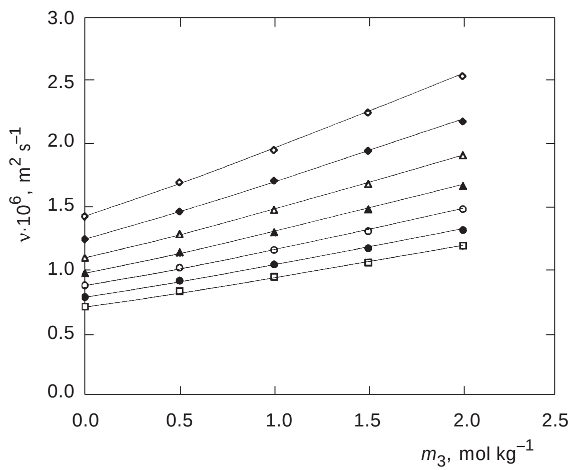

FIG. 2

Kinematic viscosity, ν, of aqueous solutions of AMP at 1 mol kg^{-1} concentration as function of molality of AMP-HCl m_3 and temperatures T (K): ✧ 293.1, ◆ 298.1, Δ 303.1, ▲ 308.1, ❍ 313.1, ● 318.1, ❏ 323.1

The authors thank the Xunta de Galicia (Spain) for partial financial support under project PGIDT00PXI20905PR.

REFERENCES

1. Rinker E., Ashour S., Sandall O.: *Chem. Eng. Sci.* **1995**, *50*, 755.
2. Pani F., Gaunand A., Cadours R., Boullau Ch., Richopn D.: *J. Chem. Eng. Data* **1997**, *42*, 353.
3. Hagewiesche D., Ashour S., Al-Ghawas H., Sandall O.: *Chem. Eng. Sci.* **1995**, *50*, 1071.
4. Dawodu O., Meisen A.: *Can. J. Chem. Eng.* **1996**, *74*, 960.
5. Messaoudi B., Sada E.: *J. Chem. Eng. Jpn.* **1996**, *29*, 534.
6. Xu S., Wang Y., Otto F., Mather A.: *Chem. Eng. Sci.* **1996**, *51*, 841.
7. Py X., Roizard C., Bergault J., Mideux N.: *Trans. Chem. Eng.* **1995**, *73*, 253.
8. Saha A., Bondyopadhyah S., Biswas A.: *Chem. Eng. Sci.* **1995**, *50*, 3587.
9. Vázquez G., Chenlo F., Vázquez M. J., del Río A.: *CHISA 1996. Proc. 12th Int. Cong. Chem. Process Eng., Prague (Czech Republic), August 25–30, 1996*, p. 1499. EFChE, Prague 1996.
10. Vázquez G., Chenlo F., Vázquez M. J., del Río A.: *Proc. 2nd Eur. Cong. Chem. Eng., Montpellier (France), October 5–7, 1999* (G. Flamant, Ed.), Vol. 66. SFGP, Nancy 1999.
11. Vázquez G., Chenlo F., Vázquez M. J.: *CHISA 2000. Proc. 14th Int. Cong. Chem. Process Eng., Prague (Czech Republic), August 27–31, 2000* (J. Novosad, Ed.), (CD-ROM). EFChE, Prague 2000.
12. Chenlo F., Moreira R., Pereira G., Vázquez M. J., Santiago E.: *J. Chem. Eng. Data* **2001**, *46*, 276.
13. Vázquez G., Chenlo F., Alvarez E., Moreira R., Pardo P.: *J. Chem. Eng. Data* **1994**, *39*, 87.
14. Marsh K. N.: *Recommended Reference Materials for the Realization of Physicochemical Properties*, p. 45. Blackwell Scientific Engineering, Oxford 1987.