Densities and Viscosities of Monoethanolamine + Ethylene Glycol + Water

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Densities and viscosities of mixtures of monoethanolamine (MEA) + ethylene glycol (EG) + water were measured at temperatures of (30, 40, 50, 60, and 70) °C. The concentration ranges were 0 to 84.7 mass % for both water and EG at 15.3 mass % MEA and 0 to 70.0 mass % for both water and EG at 30.0 mass % MEA. The experimental values were correlated as functions of temperature. The maximum deviations were less than 0.01% for densities and 0.4% for viscosities.

Introduction

Aqueous monoethanolamine (MEA) solutions are the most frequently used chemical absorbents because of high reactivity to such chemicals as carbon dioxide and hydrogen sulfide. However, the highly MEA-concentrated aqueous solution cannot be solely used for the removal of acid gases, since it can react with unrelated materials such as reactor vessels, tubing lines, and several process compartments. The use of mixed solutions of chemical and physical absorbents may provide the potential advantage capable of solving this problem. Sulfolane has been often treated as a powerful physical absorbent which can enhance the solubility of hydrogen sulfide in aqueous alkanolamine solutions (Roberts and Mather, 1988; Chakma, 1993).

In the previous work (Song et al., 1996), we reported the solubility of carbon dioxide in aqueous MEA solutions mixed with EG and poly(ethylene glycol) as physical absorbents. The physical properties of aqueous solutions of alkanolamines + physical absorbents, such as density, viscosity, and surface tension, are required for the design of acid gas treatment equipment and for measuring other physical properties such as liquid diffusivities, free-gas solubility, and reaction rate constants. Li and Lie (1994) reported the densities and viscosities of the blended amine solutions. Also, Li and Shen (1992) reported the densities of the MEA + *N*-methyldiethanolamine aqueous solutions, and DiGuilio et al. (1992), the densities and viscosities of the pure MEA.

In present study, we provide the densities and viscosities of aqueous MEA solutions mixed with EG at temperatures ranging from 30 to 70 °C.

Experimental Section

Densities were measured by using a calibrated pycnometer having a bulb volume of 25 cm^3. A water bath was used to maintain a constant temperature of the pycnometer containing liquid solutions. The temperatures of the water bath could be kept constant within ±0.05 K by an externally circulating refrigerator/heater. A Sartorius R120S balance with a precision of ±0.0001 g was used for mass measurements of liquid mixtures. The density values were reproducible within ±0.0002 g cm^{-3}.

Kinematic viscosities were measured with several Ubbelohde type viscometers (Witeg) of various capillary sizes. The calibration of these viscometers was based on the values of water and the methods used in accordance with ASTM published standards. The measurements were performed in a constant-temperature water bath controlled

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Table 1. Densities and Viscosities of Pure Monoethanolamine

	ρ/g·cm^{-3}		η/mPa·s	
t/°C	this work	lit.[a]	this work	lit.[b]
30	1.0091	1.0098	15.1940	15.1088
40	1.0013	1.0009	10.0283	10.0209
50	0.9934	0.9929	6.9463	6.9715
60	0.9854	0.9849	5.0454	5.0473
70	0.9774	0.9771	3.8050	3.7793

[a] Literature values reported by Li and Shen (1992). [b] Literature values reported by DiGuilio et al. (1992).

Table 2. Densities (ρ/g·cm^{-3}) of Monoethanolamine (1) + Ethylene Glycol (2) + Water (3) Systems (w_1 = 15.3%)

	w_2/w_3					
t/°C	0/84.7	15/69.7	30/54.7	45/49.7	60/24.7	84.7/0
30	1.0013	1.0208	1.0402	1.0584	1.0737	1.0932
40	0.9974	1.0160	1.0345	1.0520	1.0670	1.0860
50	0.9928	1.0107	1.0286	1.0454	1.0601	1.0789
60	0.9875	1.0047	1.0220	1.0386	1.0529	1.0716
70	0.9820	0.9990	1.0156	1.0315	1.0456	1.0642

Table 3. Densities (ρ/g·cm^{-3}) of Monoethanolamine (1) + Ethylene Glycol (2) + Water (3) Systems (w_1 = 30.0%)

	w_2/w_3						
t/°C	0/70	15/55	30/40	45/25	60/10	70/0	0/70[a]
30	1.0083	1.0276	1.0455	1.0610	1.0732	1.0798	1.0081
40	1.0035	1.0220	1.0392	1.0542	1.0661	1.0727	1.0034
50	0.9982	1.0160	1.0327	1.0472	1.0589	1.0654	0.9980
60	0.9924	1.0097	1.0257	1.0400	1.0516	1.0581	0.9921
70	0.9863	1.0029	1.0185	1.0327	1.0442	1.0507	0.9886

[a] Literature values reported by Li and Shen (1992).

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Table 4. Viscosities (η/mPa·s) of Monoethanolamine (1) + Ethylene Glycol (2) + Water (3) Systems (w_1 = 15.3%)

	w_2/w_3					
t/°C	0/84.7	15/69.7	30/54.7	45/49.7	60/24.7	84.7/0
30	1.270	1.890	2.847	4.415	7.016	16.74
40	1.002	1.461	2.140	3.257	5.022	11.41
50	0.8163	1.165	1.675	2.475	3.732	8.112
60	0.6807	0.9542	1.336	1.945	2.842	5.893
70	0.5806	0.7910	1.108	1.562	2.241	4.460

Table 5. Viscosities (η/mPa·s) of Monoethanolamine (1) + Ethylene Glycol (2) + Water (3) Systems (w_1 = 30.0%)

	w_2/w_3						
t/°C	0/70	15/55	30/40	45/25	60/10	70/0	0/70[a]
30	2.096	3.210	5.196	8.328	13.96	19.61	2.109
40	1.595	2.391	3.735	5.852	9.513	13.08	1.616
50	1.260	1.834	2.817	4.252	6.746	9.172	1.277
60	1.032	1.457	2.197	3.198	4.903	6.636	1.035
70	0.8560	1.182	1.723	2.485	3.718	4.928	0.868

[a] Literature values reported by Li and Lie (1994).

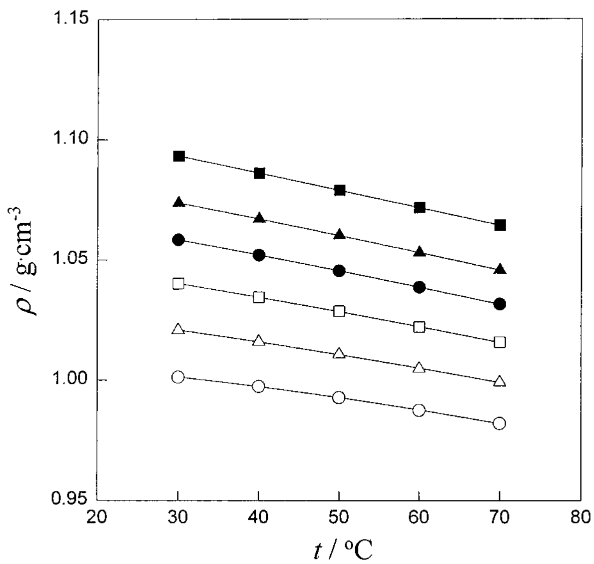

Figure 1. Densities ρ of MEA (15.3 mass %) + EG + water solutions as a function of temperature (mass % EG/mass % water): ○, 0/84.7; △, 15/69.7; □, 30/54.7; ●, 45/39.7; ▲, 60/24.7; ■, 84.7/0. Solid lines are calculated by eq 1.

to within ±0.05 K. An electronic stopwatch with an accuracy of 0.01 s was used to measure the efflux times of liquid solutions. The efflux times for one liquid sample were measured at least five times. The accuracy of the measured kinematic viscosity was estimated to be within ±1.0%. The dynamic viscosities were calculated by multiplying the measured kinematic viscosities with the density values of the same solutions. The chemical and physical absorbents used in this study were obtained from Sigma-Aldrich Chemical Co. with a minimum purity of 99 mol % and were used without further purification. All solutions were prepared with distilled water.

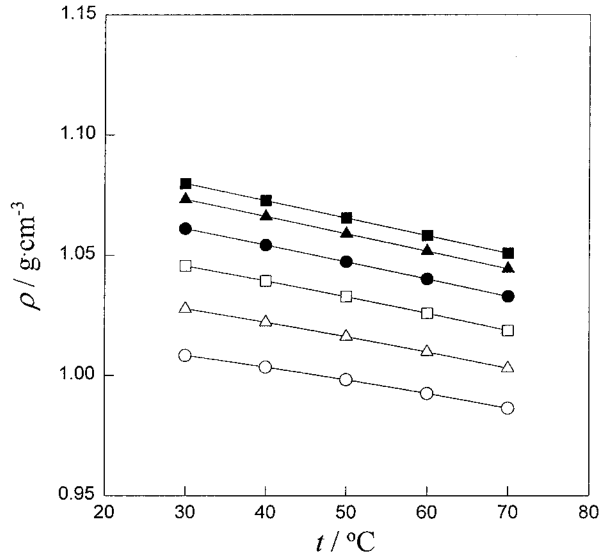

Figure 2. Densities ρ of MEA (30.0 mass %) + EG + water solutions as a function of temperature (mass % EG/mass % water): ○, 0/70; △, 15/55; □, 30/40; ●, 45/25; ▲, 60/10; ■, 70/0. Solid lines are calculated by eq 1.

Results and Discussion

In Table 1, the densities and viscosities of pure MEA over the temperature range of 30 to 70 °C were measured and compared with the recent literature data (Li and Shen, 1992; DiGuilio et al., 1992). The difference between this study and the literature was 0.048% for densities and 0.34% for viscosities in AADs. Both data sets were found to be in good agreement with literature values, which ensures that our experimental apparatus and measurement procedures can be used with reliability.

The density values of (15.3 and 30.0) mass % MEA aqueous solutions mixed with EG were listed in Tables 2 and 3, respectively. The data were regressed using the following polynomial:

$$\rho/\mathrm{g{\cdot}cm^{-3}} = a_1 + a_2(T/\mathrm{K}) + a_3(T/\mathrm{K})^2 \qquad (1)$$

Each set of the determined parameters and average absolute deviations (AAD) between the measured and calculated values were presented in Table 6. The maxi-

Table 6. Parameters and AADs for Density Correlations for Monoethanolamine (1) + Ethylene Glycol (2) + Water (3) Systems

	w_2/w_3											
	0/84.7	15/69.7	30/54.7	45/49.7	60/24.7	84.7/0	0/70	15/55	30/40	45/25	60/10	70/0
a_1	0.8586	1.0015	1.0712	1.1432	1.1754	1.2681	0.9450	1.0140	1.0792	1.1865	1.2410	1.2559
10^4a_2	13.152	6.0500	3.5236	0.6656	−0.1060	−4.4704	8.7996	6.2932	3.8668	−1.5408	−4.0188	−4.5104
10^6a_3	−2.7857	−1.7857	−1.5000	−1.1429	−1.0714	0.4286	−2.2143	−1.9286	−1.6429	−0.8571	−0.5000	−0.4286
AAD/%	0.008	0.010	0.008	0.002	0.002	0.004	0.006	0.002	0.002	0.002	0.001	0.002

Table 7. Parameters and AADs for Viscosity Correlations for Monoethanolamine (1) + Ethylene Glycol (2) + Water (3) Systems

	w_2/w_3											
	0/84.7	15/69.7	30/54.7	45/49.7	60/24.7	84.7/0	0/70	15/55	30/40	45/25	60/10	70/0
b_1	−3.150	−3.624	−3.140	−3.746	−3.967	−4.597	−2.954	−3.644	−3.467	−4.148	−4.696	−4.140
b_2	451.3	665.7	573.7	843.6	987.8	1364	463.7	733.6	750.8	1046	1328	1186
b_3	170.0	146.9	166.1	141.9	136.1	119.2	117.6	150.6	156.3	136.3	122.0	136.4
AAD/%	0.08	0.18	0.23	0.12	0.16	0.23	0.17	0.11	0.39	0.27	0.20	0.31

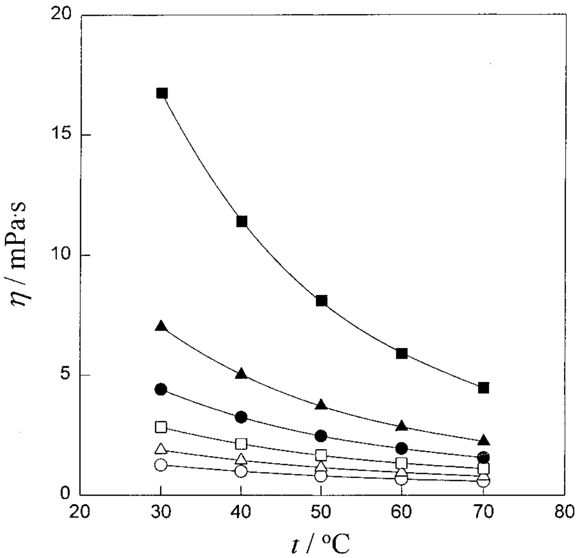

Figure 3. Viscosities η of MEA (15.3 mass %) + EG + water solutions as a function of temperature (mass % EG/mass % water): ○, 0/84.7; △, 15/69.7; □, 30/54.7; ●, 45/39.7; ▲, 60/24.7; ■, 84.7/0. Solid lines are calculated by eq 2.

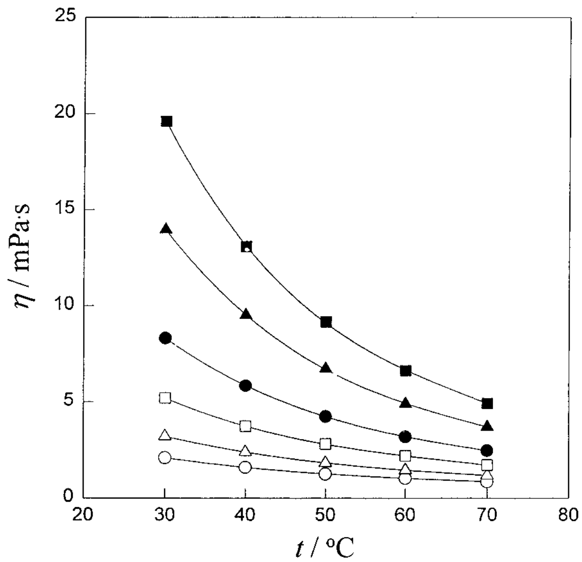

Figure 4. Viscosities η of MEA (30.0 mass %) + EG + water solutions as a function of temperature (mass % EG/mass % water): ○, 0/70; △, 15/55; □, 30/40; ●, 45/25; ▲, 60/10; ■, 70.0. Solid lines are calculated by eq 2.

mum deviation was found to be less than 0.01%. The binary density data of the 30.0 mass % MEA aqueous solution were compared with the literature data (Li and Shen, 1992) and agreed well within 0.062% in AADs. Figures 1 and 2 show the comparisons of the experimentally measured and the calculated densities for 15.3 and 30.0 mass % MEA aqueous solutions mixed with EG, respectively.

The viscosities of 15.3 and 30.0 mass % MEA aqueous solutions mixed with EG were presented in Tables 4 and 5, respectively. The following simple expression was used for regressing the data:

$$\eta/\text{mPa}\cdot\text{s} = \exp\left[b_1 + \frac{b_2}{T/\text{K} + b_3}\right] \qquad (2)$$

Table 7 includes the determined parameters and AADs between the measured and calculated values. The maximum deviation was found to be less than 0.40%. The binary viscosity data of the 30 mass % MEA aqueous solution were compared with the literature data (Li and Lie, 1994) and agreed well within 0.98% in AADs. The comparisons between the calculated and measured viscosities were also graphically shown in Figures 3 and 4 for 15.3 and 30.0 mass % MEA aqueous solutions mixed with EG, respectively.

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