Density and Viscosity of Monoethanolamine + Water + Carbon Dioxide from (25 to 80) °C

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Densities and dynamic viscosities in liquid solutions of monoethanolamine (MEA), water, and carbon dioxide (CO_2) have been measured. The mass fraction of MEA in water was (20, 30, and 40) %, and CO_2 loading was between (0 and 0.5) mol CO_2 per mole MEA; the temperature was varied between (25 and 80) °C. These measurements were compared with literature data of solutions without CO_2 and with data for CO_2 loaded solutions primarily at 25 °C. The results show that the densities and viscosities increase significantly with increasing CO_2 loading at all temperatures. The measured data for the ternary system were compared with available density and viscosity correlations from Weiland et al. *J. Chem. Eng. Data* **1998**, *43*, 378−382. Agreement between the measurements and the Weiland correlations was satisfactory. The deviation increases with increased MEA concentration, CO_2 loading, and temperature.

Introduction

Monoethanolamine (MEA) has been used for the absorption of acid gases since 1930. The mass fraction of solutions was generally increased to 30 % by 1970, and this has been standard since then. Recent attention given to CO_2 capture from exhaust gases to avoid global warming has caused renewed interest in MEA because of its high affinity for CO_2 absorption. Very large absorbent flows would need to be circulated. A further increase in solution concentration would help to reduce these flows.

Densities and viscosities for these solutions are needed to perform engineering calculations. The use of such data is typically for dimensioning the column diameter, velocities, and pressure drop in a column as described by Eckert[1] and the calculation of mass transfer correlations and mass transfer area as described by Wang et al.[2] Further use of such data are for dimensioning pipes, pumps, and heat exchangers. The only source of density and viscosity data found for the ternary system MEA, water, and CO_2 is Weiland et al.[3] where data at 25 °C are presented. The present work was undertaken to extend the range of data available and thus make investigation of more concentrated solutions easier. Data with a mass fraction of MEA from (0 to 100) % were measured from (25 to 80) °C. Also included in the present work are measurements of densities and viscosities for solutions with CO_2 loadings up to $\alpha = 0.50$. α is moles of CO_2 per mole of amine in the solution. Loadings of CO_2 in the densimeter had to be limited at higher temperatures. The higher the MEA content, the lower the temperature had to be at $\alpha = 0.50$. There seemed to be problems with degassing as the temperature increased.

The binary MEA + water density data were regressed using a Redlich−Kister equation as in Lee and Lin.[4] The binary viscosity data were regressed using a McAllister equation also found in Lee and Lin. The measured data in the ternary system were compared with correlations presented in Weiland et al.[3] There was no case for making new correlations as the data were well-represented by the existing ones.

Experimental Section

MEA was purchased from Merck with a purity (assay) ≥ 99.5 %. Unloaded solutions were prepared by adding deionized water. Loaded solutions were prepared by bubbling CO_2 from a gas bottle through a sintered glass, into a batch of the unloaded solutions. The saturated solutions were analyzed to determine the CO_2 loading. The saturated solutions were then mixed together with unloaded solutions to produce a set of samples with a fixed MEA composition at varying loadings. All samples (of approximately 500 g) were prepared by using an analytical balance with an accuracy of ± 0.1 mg. Some of the diluted samples were checked by using an analysis method based on the precipitation of $BaCO_3$. In this 0.5 g of the loaded sample was mixed with 41.7 cm^3 of 0.3 M $BaCl_2$ and 50 cm^3 of 0.1 M NaOH. The mixture was boiled for approximately 5 min, before being cooled down to ambient temperature. The sample was then filtrated, and the filter cake was added to 50 cm^3 of degassed, deionized water before titration with 0.1 M HCl to pH 2. Stirring is important to ensure that all $BaCO_3$ particles are dissolved. The sample was then titrated with 0.1 M NaOH to pH 5.3, which is the end point for the acid−base titration. The sample masses and volumes of HCl and NaOH added by titration are used for the calculation of CO_2 loading.

Densities of the MEA (1) + H_2O (2) + CO_2 (3) solutions were measured using an Anton Paar density meter (DMA 4500), with a specified repeatability of ± 0.00001 $g \cdot cm^{-3}$. The uncertainty in the density measurement is estimated to be ± 0.00005 $g \cdot cm^{-3}$. The specified repeatability of the integrated temperature measurement is specified as ± 0.01 K, and the estimated uncertainty is ± 0.03 K. The estimated uncertainty in mass fraction of MEA is 0.5 %, and the estimated uncertainty in CO_2 loading is 2 %. Calibrations based on known densities made it possible to measure the density in the unknown samples. Measurements at high temperature with the highest loadings

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Table 1. Density ρ for MEA (1) + H_2O (2) from t = (25 to 80) °C as a Function of Mass Fraction MEA w_1

t	w_1						
°C	20 %	30 %	40 %	50 %	70 %	90 %	100 %
				ρ/g·cm^{-3}			
25	1.0053	1.0106	1.0158	1.0208	1.0262	1.0200	1.0123
40	0.9991	1.0034	1.0077	1.0117	1.0155	1.0084	1.0003
50	0.9943	0.9981	1.0018	1.0053	1.0082	1.0006	0.9923
70	0.9830	0.9858	0.9889	0.9915	0.9930	0.9846	0.9760
80	0.9766	0.9794	0.9819	0.9842	0.9850	0.9764	0.9678

Table 2. Density ρ for MEA (1) + H_2O (2) + CO_2 (3) from t = (25 to 80) °C and CO_2 Loading from α = (0.1 to 0.5) n_{CO_2}/n_{MEA} at Mass Fraction MEA = 20 %

t	α				
°C	0.1	0.2	0.3	0.4	0.5
			ρ/g·cm^{-3}		
25	1.0188	1.0327	1.0476	1.0640	1.0800
40	1.0125	1.0264	1.0413	1.0579	1.0735
50	1.0076	1.0215	1.0364	1.0530	1.0680
70	0.9965	1.0105	1.0254	1.0419	1.0570
80	0.9902	1.0043	1.0192	1.0360	

Table 3. Density ρ for MEA (1) + H_2O (2) + CO_2 (3) from t = (25 to 80) °C and CO_2 Loading from α = (0.1 to 0.5) n_{CO_2}/n_{MEA} at Mass Fraction MEA = 30 %

t	α				
°C	0.1	0.2	0.3	0.4	0.5
			ρ/g·cm^{-3}		
25	1.0280	1.0480	1.0700	1.0957	1.1211
40	1.0210	1.0410	1.0629	1.0885	1.1140
50	1.0160	1.0355	1.0580	1.0830	1.1080
70	1.0040	1.0240	1.0464	1.0719	
80	0.9970	1.0176	1.0402	1.0660	

Table 4. Density ρ for MEA (1) + H_2O (2) + CO_2 (3) from t = (25 to 80) °C and CO_2 Loading from α = (0.1 to 0.5) n_{CO_2}/n_{MEA} at Mass Fraction MEA = 40 %

t	α				
°C	0.1	0.2	0.3	0.4	0.5
			ρ/g·cm^{-3}		
25	1.0380	1.0630	1.0930	1.1285	1.1597
40	1.0300	1.0550	1.0850	1.1210	
50	1.0240	1.0490	1.0797	1.1150	
70	1.0120	1.0370	1.0680	1.1040	
80	1.0050	1.0310	1.0620	1.0977	

Table 5. Viscosity η for MEA (1) + H_2O (2) from t = (25 to 80) °C as a Function of Mass Fraction MEA w_1

t	w_1						
°C	20 %	30 %	40 %	50 %	70 %	90 %	100 %
				η/mPa·s			
25	1.70	2.48	3.58	5.51	12.46	19.40	17.90
40	1.18	1.67	2.28	3.39	6.96	10.20	9.61
50	0.95	1.33	1.75	2.54	4.94	7.06	6.72
70	0.67	0.92	1.14	1.57	2.79	3.81	3.69
80	0.58	0.77	0.95	1.28	2.18	2.93	2.85

Table 6. Viscosity η for MEA (1) + H_2O (2) + CO_2 (3) from t = (25 to 80) °C and CO_2 Loading from α = (0.1 to 0.5) n_{CO_2}/n_{MEA} at Mass Fraction MEA = 20 %

t	α				
°C	0.1	0.2	0.3	0.4	0.5
			η/mPa·s		
25	1.8	1.9	1.9	2.1	2.2
40	1.3	1.3	1.3	1.4	1.6
50	1.0	1.0	1.1	1.2	1.3
70	0.7	0.7	0.8	0.8	0.9
80	0.6	0.6	0.7	0.7	0.8

Table 7. Viscosity η for MEA (1) + H_2O (2) + CO_2 (3) from t = (25 to 80) °C and CO_2 Loading from α = (0.1 to 0.5) n_{CO_2}/n_{MEA} at Mass Fraction MEA = 30 %

t	α				
°C	0.1	0.2	0.3	0.4	0.5
			η/mPa·s		
25	2.6	2.9	3.1	3.5	3.9
40	1.7	2.0	2.0	2.4	2.7
50	1.4	1.6	1.6	1.9	2.1
70	0.9	1.1	1.1	1.3	1.5
80	0.8	0.9	0.9	1.1	1.3

Table 8. Viscosity η for MEA (1) + H_2O (2) + CO_2 (3) from t = (25 to 80) °C and CO_2 Loading from α = (0.1 to 0.5) n_{CO_2}/n_{MEA} at Mass Fraction MEA = 40 %

t	α				
°C	0.1	0.2	0.3	0.4	0.5
			η/mPa·s		
25	4.0	4.6	5.1	6.0	7.0
40	2.5	3.0	3.3	4.0	4.6
50	2.0	2.3	2.6	3.1	3.8
70	1.3	1.5	1.7	2.0	2.3
80	1.1	1.3	1.4	1.7	1.9

were impossible because of the formation of gas bubbles. Densities for w_1 = 20 % at 80 °C, w_1 = 30 % at (70 and 80) °C, and w_1 = 40 % above 25 °C, all at α = 0.5, were therefore not measured.

Dynamic viscosities of the MEA solutions were measured using a Viscometer (Z1DIN), with an estimated measurement uncertainty of ± 0.01 mPa·s. The integrated temperature measurement is specified with a resolution of ± 0.01 K, and the estimated uncertainty is ± 0.03 K. The uncertainty in the compositions is the same as for the density measurements.

Mixtures with w_1 = (20, 30, 40, 50, 70, 90, and 100) % were measured at (25, 40, 50, 70, and 80) °C. CO_2 loaded solutions for w_1 = (20, 30, and 40) % (w_1 is on a basis without CO_2) with α from 0 to 0.5 were measured at (25, 40, 50, 70, and 80) °C. Both densities and viscosities were measured for each solution except as explained above.

Results

The results from the experimental work are presented in tables, densities in Tables 1, 2, 3, and 4 and viscosities in Tables 5, 6, 7, and 8.

Discussion

The density data for unloaded solutions have been compared to literature data from Leibush and Shorina[5] at w_1 = (20 and 40) %, and the agreement is satisfactory. The maximum deviation is less than 0.3 %.

The binary density data have been regressed by least-squares minimization to a Redlich−Kister equation. Equations 1 to 3 defining excess molar volume and the Redlich−Kister equation are taken from Lee and Lin.[4] Data for pure water are taken from NIST.[6]

$$V^E = V - (x_1 \cdot V_1 + x_2 \cdot V_2) \tag{1}$$

$$V = (x_1 \cdot M_1 + x_2 \cdot M_2)/\rho \tag{2}$$

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

V is the molar volume of the solution, and x_i and M_i are the mole fraction and molecular mass for component i. The resulting

Table 9. Regressed Parameters of Redlich−Kister Excess Volume Correlation, Equation 3, for MEA (1) + H_2O (2)

t / °C	A_0	A_1	A_2	A_3	ARD / %
25	−2.5263	0.7404	0.5698	−1.6062	0.005
40	−2.4787	0.6135	0.6018	−1.2561	0.002
50	−2.4630	0.5338	0.6420	−0.9870	0.002
70	−2.4541	0.4324	0.7030	−0.6392	0.005
80	−2.4070	0.4664	0.5390	−0.7186	0.003

Table 10. Parameters (from Weiland et al.[3]) of Density Correlation, Equations 4 to 6

A	−1.8218
B	0
C	0
D	$-5.35162 \cdot 10^{-7}$
E	$-4.51417 \cdot 10^{-4}$
F	1.19451
M_1	61.08
V_3	0.04747
std. dev.	0.00221

Redlich−Kister parameters are given in Table 9 and are in the same area as the parameters presented by Lee and Lin.[4] The ARD (average relative deviation) values (average of $(\rho - \rho_{reg})/\rho$) for the data points are below 0.01 % for all of the temperatures. Lee and Lin[4] report ARD values between (0.01 and 0.02) %. The accuracy in data from this work is satisfactory.

The density data for loaded mixtures at 25 °C are compared with data from Weiland et al.[3] in Figure 1. The maximum deviation is less than 1 % (or 0.01 $g \cdot cm^{-3}$). The density data for a mixture loaded with 0.1 mol CO_2 per mole MEA at (25, 40, and 50) °C have been compared with values from Kohl and Nielsen[8] in Figure 2. The measured densities in this work are between (0.2 and 0.4) % lower than the data from Kohl and Nielsen. This deviation is less than the deviation between this work and the Weiland data.

In Table 1, the density of a solution of MEA and water shows a maximum density at $w_1 = 70$ %. The same effect is seen in the data from Lee and Lin.[4] This might be explained by some complex formation between molecules and ionic species in the solution.

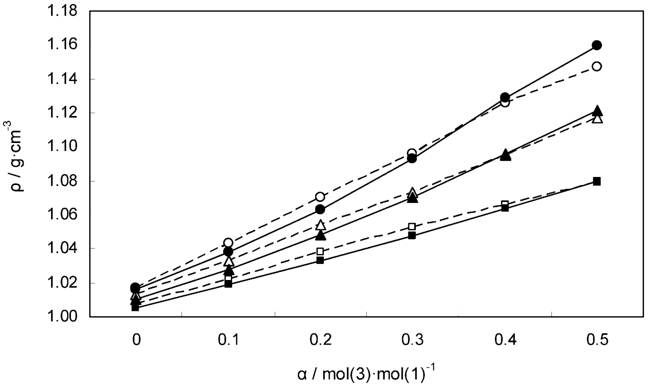

Figure 1. Density for MEA (1) + water (2) + CO_2 (3) as a function of CO_2 loading α at w_1 = (20, 30, and 40) mass % at 25 °C. Results from this work (solid line): ■, w_1 = 20 %; ▲, w_1 = 30 %; ●, w_1 = 40 %; are compared to results from Weiland[3] (dashed line): □, w_1 = 20 %; △, w_1 = 30 %; ○, w_1 = 40 %.

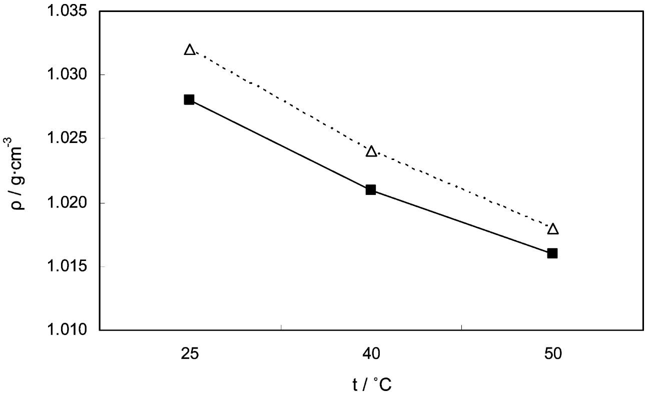

Figure 2. Density for MEA (1) + water (2) + CO_2 (3) at w_1 = 30 % and CO_2 loading α = 0.1 mol/mol at (25, 40, and 50) °C. Solid line, ■, the results from this work; are compared to: dashed line, △, results from Kohl and Nielsen.[8]

A correlation for estimating the density in alkanolamine mixtures is suggested by Weiland et al.[3] The correlation is described by eqs 4 to 6:

$$\rho = \frac{\sum_{i=1}^{3} (x_i \cdot M_i)}{V} \qquad (4)$$

$$V/(cm^3 \cdot mol^{-1}) = x_1 \cdot V_1 + x_2 \cdot V_2 + x_3 \cdot V_3 + x_1 \cdot x_2 \cdot A + x_1 \cdot x_3 \cdot (B + C \cdot x_1) \qquad (5)$$

$$V_1/(cm^3 \cdot mol^{-1}) = \frac{M_1}{D \cdot (T/K)^2 + E \cdot (T/K) + F} \qquad (6)$$

Data for the necessary parameters are given in Table 10. The last term of eq 5 is 0 for MEA because the parameters B and C are 0 for MEA.

At 25 °C, the maximum deviation between experimental data in this work and the correlation is 1.1 %, and accordingly the agreement among this work, Weiland's data, and the correlation is satisfactory. The maximum deviation between the measured data in this work and the correlation is 1.6 % at 80 °C. This shows that Weiland's density correlation is satisfactory over the whole range. If it is assumed that the experimental data have an uncertainty well below 1 %, this implies that the correlation is less accurate at a higher temperature.

The viscosity data for unloaded solutions have been compared to literature data[4,7,10] at w_1 = 30 %. The agreement is satisfactory, and the maximum relative deviation is less than 1 % between the present data and the data of Maddox;[10] the maximum relative deviation between the present data and the data of Mandal et al.[7] is about 2 %.

The binary viscosity data for MEA and water have been regressed by least-squares minimization using the McAllister equation given in eq 8. Equations 7 and 8 are found in Lee and Lin,[4] and ν is the kinematic viscosity for the solution.

$$\nu = \eta/\rho \qquad (7)$$

$$\ln(\nu/(m^2 \cdot s^{-1}) \cdot 10^{-6}) = x_1^3 \cdot \ln \nu_1 + 3 \cdot x_1^2 \cdot x_2 \cdot \ln \nu_{12} + 3 \cdot x_1 \cdot x_2^2 \cdot \ln \nu_{21} + x_2^3 \cdot \ln \nu_2 - \ln[x_1 + x_2(M_2/M_1)] + 3 \cdot x_1^2 \cdot x_2 \cdot \ln[(2 + M_2/M_1)/3] + 3x_1 \cdot x_2^2 \cdot \ln[(1 + 2 \cdot M_2/M_1)/3] + x_2^3 \cdot \ln(M_2/M_1) \qquad (8)$$

The resulting parameters are given in Table 11. The McAllister parameters are comparable to the parameters from Lee and Lin, and the ARD values obtained are close. ARD (average of $(\eta - \eta_{reg})/\eta$) varies from (0.37 to 0.82) % in Lee and Lin and from (0.66 to 0.75) % in this work up to 50 °C. At higher temperatures, the ARD in this work increases to 1.4 %. In Table 5, the viscosity of a solution of MEA and water shows a

Table 11. Regressed Parameters of McAllister Kinematic Viscosity Correlation, Equation 8, for MEA (1) + H_2O (2)

t / °C	ν_{12}	ν_{21}	ARD / %
25	20.6322	32.3436	0.71
40	10.5798	17.2850	0.66
50	7.3017	11.7970	0.75
70	3.9003	6.3415	1.21
80	2.9997	4.8615	1.36

maximum viscosity at $w_1 = 90$ %. This might be explained by some complex formation between molecules and ionic species in the solution, as suggested for explaining the density maximum at $w_1 = 70$ %.

The viscosity data for loaded mixtures at 25 °C are compared with data from Weiland et al.[3] in Figure 3. The maximum deviation is less than 0.3 mPa·s or 7 % relative deviation at $w_1 = 40$ %. The maximum deviation is less than 0.12 mPa·s or 4 % at $w_1 = 30$ %.

A correlation for estimating the dynamic viscosity in alkanolamine mixtures compared to the water viscosity is suggested by Weiland et al.[3]

$$\frac{\eta}{\eta_2} = \exp\left(\frac{[(a \cdot w_1 + b) \cdot (T/\mathrm{K}) + (c \cdot w_1 + d)] \times [\alpha(e \cdot w_1 + f \cdot (T/\mathrm{K}) + g) + 1]w_1}{(T/\mathrm{K})^2}\right) \tag{9}$$

where α is the CO_2 loading and the parameters a to g are given in Table 12.

Values for η_2 are necessary in this correlation. η_2 is calculated from a correlation from Swindells taken from Weast:[9]

$$\log_{10} \frac{\eta_2}{\eta_{2,20}} = \frac{1.3272(20 - (t/°\mathrm{C}) - 0.001053((t/°\mathrm{C}) - 20)^2}{(t/°\mathrm{C}) + 105} \tag{10}$$

$\eta_{2,20}$ is the pure water viscosity at 20 °C, which is 1.0020 mPa·s in Swindells' original correlation. The resulting viscosities have been compared to viscosity data from NIST.[6] The maximum deviation was 0.0005 mPa·s or 0.12 % relative deviation, and this deviation is regarded to be neglible when used in a mixture viscosity correlation. The Weiland correlation has been used to estimate the viscosity for the conditions in the experiments. Figure 4 shows measurements from Weiland and from this work compared to the correlation at 25 °C.

The agreement is satisfactory (maximum 0.39 mPa·s or 5 % relative deviation between this work and the correlation). At $w_1 = 40$ %, the data in this work are closer to Weiland's correlation than Weiland's measurements. The maximum deviation between Weiland's data and Weiland's correlation is 13 %. Weiland's viscosity correlation probably overpredicts the viscosity at $w_1 = 40$ % because the correlation gives higher viscosities than experimental data from both Weiland and this work.

Figures 5, 6, and 7 show measurements in this work from (25 to 80) °C compared to Weiland's correlation at $w_1 = (20, 30, \text{and } 40)$ %. The agreement is satisfactory, but Weiland's viscosity correlation probably overpredicts the viscosity at $w_1 = 40$ % because the correlation gives higher viscosities than experimental data from both Weiland and this work.

The maximum relative deviation in all of the viscosity measurements in this work is 10 % compared to Weiland's correlation. The highest deviations are at high MEA mass fractions, high loadings, and high temperatures. The maximum deviation between this work and the correlation at $w_1 = 30$ % is 0.18 mPa·s or 5 %.

The combined uncertainty in the presented density values as a function of temperature and composition is estimated to be ± 0.05 % or ± 0.0005 $g \cdot cm^{-3}$ for the MEA + water system and ± 0.2 % or ± 0.002 $g \cdot cm^{-3}$ for the CO_2 loaded system except for the highest temperatures and CO_2 loadings. The combined relative uncertainty in the presented viscosity values is estimated to be ± 1 % (or about ± 0.01 mPa·s with water at low temperature) for the MEA + water system and ± 3 % (or about ± 0.1 mPa·s for a typical loaded system at low temperature) for the CO_2 loaded system, except for the highest

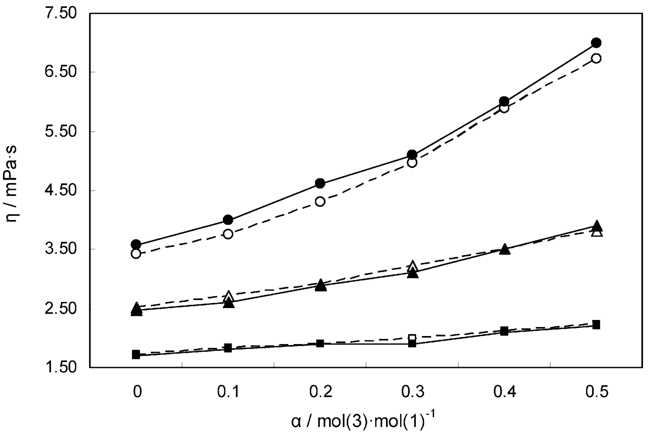

Figure 3. Viscosity for MEA (1) + water (2) + CO_2 (3) as a function of CO_2 loading α at $w_1 = (20, 30, \text{and } 40)$ mass % at 25 °C. Results from this work (solid line): ■, $w_1 = 20$ %; ▲, $w_1 = 30$ %; ●, $w_1 = 40$ %; are compared to results from Weiland[3] (dashed line); □, $w_1 = 20$ %; △, $w_1 = 30$ %; ○, $w_1 = 40$ %.

Table 12. Parameters (from Weiland et al.[3]) of Viscosity Correlation, Equation 9

a	0
b	0
c	21.186
d	2373
e	0.01015
f	0.0093
g	−2.2589
std. dev.	0.0732

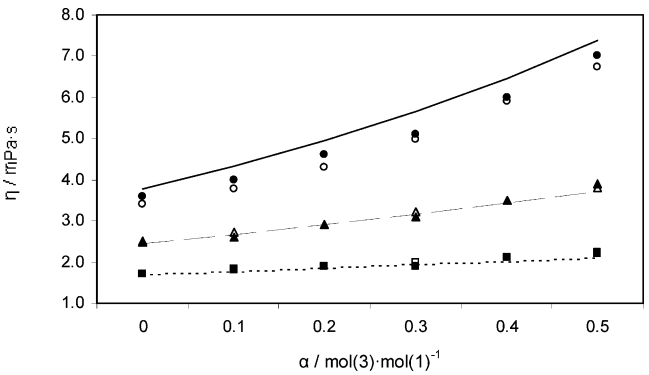

Figure 4. Viscosity for MEA (1) + water (2) + CO_2 (3) as a function of CO_2 loading α at $w_1 = (20, 30, \text{and } 40)$ mass % at 25 °C compared to Weiland's correlation. Results from this work: ■, $w_1 = 20$ %; ▲, $w_1 = 30$ %; ●, $w_1 = 40$ %; are compared to results from Weiland:[3] □, $w_1 = 20$ %; △, $w_1 = 30$ %; ○, $w_1 = 40$ %; and Weiland's correlation, eq 9: dotted line, $w_1 = 20$ %; dashed line, $w_1 = 30$ %; solid line, $w_1 = 40$ %.

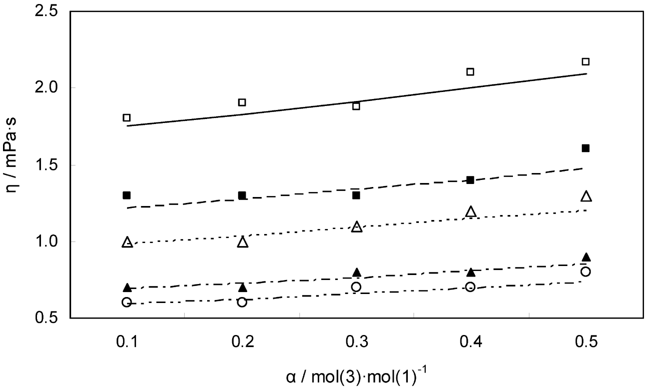

Figure 5. Viscosity for MEA (1) + water (2) + CO_2 (3) at w_1 = 20 % for (25, 40, 50, 70, and 80) °C compared to Weiland's correlation. Results from this work: □, 25 °C; ■, 40 °C; △, 50 °C; ▲, 70 °C; ○, 80 °C; are compared to Weiland's correlation, eq 9: solid line, 25 °C; dashed line, 40 °C; dotted line, 50 °C; dash−dot−dashed line, 70 °C; dot−dot−dashed line, 80 °C.

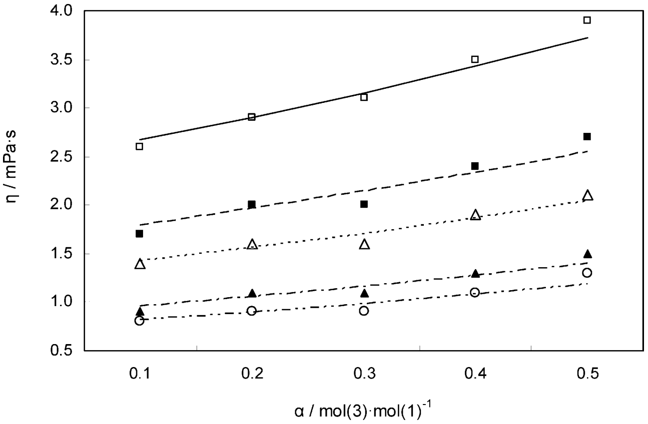

Figure 6. Viscosity for MEA (1) + water (2) + CO_2 (3) at w_1 = 30 % for (25, 40, 50, 70, and 80) °C compared to Weiland's correlation. Results from this work: □, 25 °C; ■, 40 °C; △, 50 °C; ▲, 70 °C; ○, 80 °C; are compared to Weiland's correlation, eq 9: solid line, 25 °C; dashed line, 40 °C; dotted line, 50 °C; dash−dot−dashed line, 70 °C; dot−dot−dashed line, 80 °C.

temperatures and CO_2 loadings. At the highest temperatures and CO_2 loadings, the uncertainty is higher. The main contribution to the rather high uncertainty is expected to come from the uncertainty in measuring the liquid composition. There are especially difficulties in obtaining homogeneous samples and avoiding evaporation.

Conclusions

Density and viscosity in MEA + water + CO_2 mixtures have been measured in the temperature range between (25 and 80) °C with a CO_2 loading range of (0 to 0.5) mol CO_2 per mole of MEA.

The agreement with literature data at 25 °C is satisfactory. For temperatures between (25 and 80) °C, there are few literature data. However, the agreement with Weiland's proposed correlations is satisfactory over this temperature range. The maximum relative deviation between data from this work and Weiland's density correlation is 1.6 %. The maximum relative deviation between data from this work and Weiland's viscosity correlation is 10 %. The deviations increase with increased MEA concentration, CO_2 loading, and temperature.

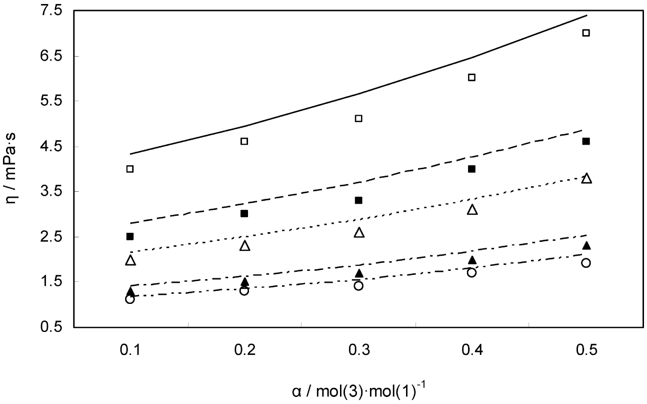

Figure 7. Viscosity for MEA (1) + water (2) + CO_2 (3) at w_1 = 40 % for (25, 40, 50, 70, and 80) °C compared to Weiland's correlation. Results from this work: □, 25 °C; ■, 40 °C; △, 50 °C; ▲, 70 °C; ○, 80 °C; are compared to Weiland's correlation, eq 9: solid line, 25 °C; dashed line, 40 °C; dotted line, 50 °C; dash−dot−dashed line, 70 °C; dot−dot−dashed line, 80 °C.

Weiland's density and viscosity correlations are regarded as satisfactory for use in estimation methods for column capacity calculations, pressure drop calculations, and mass transfer correlations.

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