Viscosities for Aqueous Solutions of *N*-Methyldiethanolamine from 313.15 to 363.15 K

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This paper presents liquid viscosities for seven binary mixtures of *N*-methyldiethanolamine + water over the entire composition range at atmospheric pressure for temperatures between 313.15 and 363.15 K. The work includes measurements of kinematic viscosities with three Cannon−Fenske viscosimeters. The viscosity deviations as a function of composition change sign from negative to positive in the water-rich region at 313.15 and 333.15 K. From 353.15 to 363.15 K, viscosity deviations are positive throughout the entire concentration range. A Redlich−Kister-type equation correlates the viscosity deviations.

Introduction

Aqueous *N*-methyldiethanolamine (MDEA) is a commonly used solvent for CO_2 and H_2S removal in gas treating. Its viscosity is an important parameter in heat exchange and mass-transfer rate-based absorb design.

DiGuilio et al.[1] and Mandal et al.[2] measured viscosities of pure MDEA in the ranges (293.1 to 424.1) K and (293.15 to 323.15) K, respectively. Al-Ghawas et al.[3] measured the viscosity of pure MDEA and aqueous MDEA solutions at concentrations between 10 and 50 mass % from (288.15 to 333.15) K. Also, Rinker et al.[4] reported the densities and viscosities at the same compositions but from (333.15 to 373.15) K. Li and Lie[5] measured the viscosity of 0.036 and 0.061 mole fraction aqueous solutions of MDEA at temperatures between (303.15 and 333.15) K. Welsh and Davis[6] measured the viscosity of a 0.13 mole fraction aqueous solution of MDEA from (283.15 to 333.15) K. Weiland et al.[7] measured the viscosity at concentrations from 0.061 to 0.185 mole fraction of MDEA at 298.15 K and Haimour and Sandall[8] reported the viscosities of this system at 0.017, 0.026, and 0.061 mole fraction from (288.15 to 308.15) K. Also, Rinker et al.[9] measured the viscosity of aqueous MDEA solutions at concentrations between 0.017 and 0.13 mole fraction at 298.15 K. Teng et al.[10] measured the viscosity at five temperatures from (298.15 to 353.15) K over the entire concentration range.

This paper reports the measured values for the viscosity of MDEA + water mixtures from 313.15 to 363.15 K and for concentrations from 0.06 to 0.74 mole fraction of MDEA. The viscosity deviations as a function of composition correlate well using a Redlich−Kister equation.

Experimental Section

We have measured the kinematic viscosity using three Cannon−Fenske viscosimeters (sizes 50, 100, and 150). The measurements follow the standard test ASTM 445. The viscometers were calibrated against water of HPLC grade and pure MDEA. The viscosimeters reside in a Polyscience constant-temperature water bath that is controlled within ±0.01 K. Temperatures are measured with a digital thermometer from Automatic System F250 with an accuracy of 0.01 K. The efflux time was measured manually with a digital stopwatch having an accuracy of 0.01 s. Each point is an average of at least five runs with a maximum deviation in the kinematic viscosity of ±0.05%, and the estimated accuracy of each measurement is ±0.5%. The kinematic viscosity is

$$v = kt \tag{1}$$

where v is the kinematic viscosity in centistokes, k is a viscosimeter-specific constant, and t is the effluent time in seconds. The absolute viscosity results from multiplying the kinematic viscosity by the density of the same sample. Densities come from Bernal-García et al.[11]

Samples

HPLC-grade water was purchased from Fischer Co. with a purity grater than 99.95 mass %, and MDEA was

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Table 1. Experimental Viscosity Values for MDEA and MDEA + Water

	$T = 313.15$ K		$T = 333.15$ K		$T = 353.15$ K		$T = 363.15$ K	
x_1	η/mPa·s	$\Delta\eta$/mPa·s	η/mPa·s	$\Delta\eta$/mPa·s	η/mPa·s	$\Delta\eta$/mPa·s	η/mPa·s	$\Delta\eta$/mPa·s
0	0.656	0	0.476	0	0.358	0	0.305	0
0.0604	1.940	−0.767	1.202	−0.105	0.813	0.049	0.687	0.082
0.0902	3.115	−0.605	1.709	−0.021	1.127	0.162	0.871	0.118
0.1293	5.108	0.060	2.703	0.429	1.630	0.403	1.205	0.257
0.2571	15.177	5.789	6.700	2.650	3.472	1.385	2.606	1.022
0.3715	24.783	11.510	10.242	4.602	4.873	2.017	3.611	1.459
0.5828	34.788	14.340	13.737	5.159	6.569	2.293	4.749	1.547
0.7430	35.917	10.028	14.488	3.683	7.084	1.730	5.278	1.279
1	34.617	0	14.377	0	7.082	0	5.277	0

Table 2. Comparison of Viscosity Values (η, in mPa·s) among Different Authors for Pure MDEA and Two Aqueous Solution

T/K	DiGuilio et al.[1]	Mandal et al.[2]	Al-Ghawas et al.[3]	Li and Lie[5]	Teng et al.[10]	this work
			$x_1 = 1.0000$			
313.15	33.928	34.31	34.78	34.309	34.110	34.617
333.15	14.337	14.39	14.50	14.386	14.300	14.377
353.15		7.088		7.088	7.115	7.082
			$x_1 = 0.0604$			
313.15		1.92	1.937	1.953	1.893	1.940
333.15	1.119		1.207	1.210	1.128	1.202
353.15	0.766				0.852	0.813
			$x_1 = 0.1293$			
313.15	5.105	5.033	5.105		5.219	5.108
353.15					1.629	1.630

Table 3. Coefficients a_i in Equation 3

T	a_0	a_1	a_2	a_3	std dev
K	mPa·s	mPa·s	mPa·s	mPa·s	mPa·s
313.15	58.064457	20.041058	−69.160583	6.819112	0.2719
333.15	21.490746	2.559216	−20.190969	10.708123	0.0967
353.15	9.389132	0.742862	−5.477211	5.434008	0.0230
363.15	6.436915	−0.156913	−1.944539	6.809300	0.0441

obtained from Huntsman Co. with a stated purity of 99 mass %. We used these samples as received. The gravimetrically prepared mixtures (using an Ohaus Model AS120S analytical balance) had a precision of ±0.1 mg. The overall uncertainty for the compositions was 0.2 mol %.

Results and Discussion

We measured the atmospheric viscosity of pure MDEA and water plus seven binary mixtures from (313.15 to 363.15) K. The viscosity values appear in Table 1. Also, the experimental values compare with measurements from DiGuilio et al.,[1] Mandal et al.,[2] Al-Ghawas et al.,[3] Rinker et al.,[4] Li and Lie,[5] Welsh and Davis,[6] Rinker et al.,[9] and Teng et al.[10] Table 2 contains a comparison of the viscosity measurements for pure MDEA and two mixtures of 0.0604 and 0.1293 MDEA mole fraction. The average percent deviation between the current measurements and the literature values is less than 0.7%. The expression used for calculating the viscosity deviations for the binary mixtures is

$$\Delta\eta = \eta - (x_1\eta_1 + x_2\eta_2) \tag{2}$$

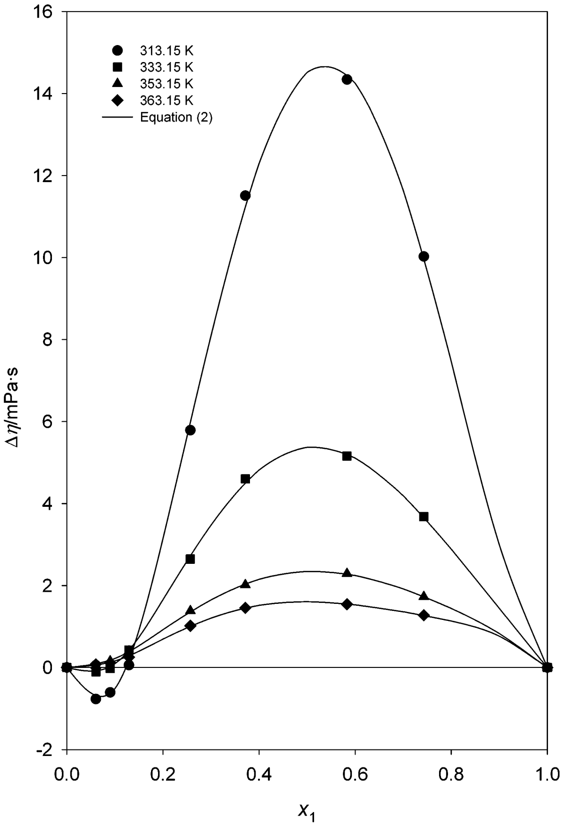

Figure 1. Viscosity deviations for MDEA aqueous solutions.

where x_1 and x_2 are the mole fractions of MDEA and water in the mixture and η, η_1, and η_2 are the viscosities of the mixture, pure MDEA, and pure water, respectively. Viscosity deviations also appear in Table 1. Figure 1 shows the dependence of $\Delta\eta$ on composition and temperature. At 0.0902 mole fraction of MDEA, viscosity deviations have an approximately constant value. Kapadi et al.[12] presents the same behavior for aqueous ethanolamine solutions, but the constant value occurs at around 0.2277 mole fraction of ethanolamine. In this work, we have negative deviations of the viscosity only at 313.15, this could be an indication of the findings of Kapadi et al.[12] in which they mention that positive deviations of the viscosity result from hydrogen-bonding interactions more than from dissociation effects. We have used a Redlich−Kister-type equation to correlate values of viscosity deviations

$$\Delta\eta = x_1 x_2 \sum a_i (x_1 - x_2)^i \qquad (3)$$

where a_i are the adjusted coefficients. Table 3 presents the values of these coefficients and the standard deviations of $\Delta\eta$ at each temperature.

Conclusions

This work presents experimental viscosities of MDEA + water at temperatures between (333.15 and 363.15) K and at concentrations ranging from 0.06 to 0.74 mole fraction of MDEA. The viscosity deviations change sign from negative to positive in the water-rich region at (313.15 and 333.15) K. At temperatures greater than 353.15 K, the viscosity deviations are positive throughout the entire concentration range.

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