Physical and Transport Properties of Aqueous Triisopropanolamine Solutions

Raj K. Chauhan, Sang Jun Yoon, and Huen Lee*

Department of Chemical and Biomolecular Engineering, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong, Yuseong-gu, Daejeon 305-701, Republic of Korea

Min Cheol Kang

Korea Energy Management Corporation, 1157 Pungdeokcheon-2dong, Yongin, Gyeonggi-do 449-994, Republic of Korea

Byoung-Moo Min

Korea Institute of Energy Research, 71-2 Jang-dong, Yuseong-gu, Daejeon 305-343, Republic of Korea

Densities, viscosities, surface tensions, and refractive indices of triisopropanolamine + water systems were measured at (303.15, 313.15, 323.15, 333.15, and 343.15) K. The amine concentrations were selected at (5.0, 10.0, 15.0, 20.0, and 25.0) mass %. The measured data for four physical and transport properties were regressed with polynomial equations. The maximum deviations were found to be less than 0.01% for densities, 0.91% for viscosities, 0.4% for surface tensions, and 0.03% for refractive indices.

Introduction

The removal of acidic gas components from gaseous streams in oil refineries, petroleum chemical plants, and the natural gas and synthetic ammonia industries has been considered as an industrially important issue. Up to date, primary and secondary amines such as monoethanolamine (MEA), diethanolamine (DEA), and diisopropanolamine (DIPA) have been widely studied and used.[1] Tertiary amines are known to have a high loading capacity for CO_2, but few examples are available in the literature. In the case of tertiary amines,[2] *N*-methyldiethanolamine (MDEA) is finding acceptance in industry for the selective removal of H_2S from gas streams containing both CO_2 and H_2S.

In the present study triisopropanolamine (TIPA), which is one of the tertiary amines, was selected as a potential absorbent. In continuation of our previous work,[3−5] we present here both physical and transport properties of H_2O + triisopropanolamine (TIPA) mixtures. The physical and transport properties of aqueous amine solutions are required for the design of acid gas treatment plants and for estimating other physical properties such as gas solubilities and reaction rate constants.

Experimental Section

Materials. Triisopropanolamine of commercial grade (98.0%) manufactured by Acros Organics was used without further purification. Spectroscopic-grade water was used for making the aqueous amine solutions.

Apparatus and Procedure. A pycnometer of volume 50 cm^3 was used to measure the densities of binary solutions over the temperature range (303.15 to 343.15) K. All the measurements were made in a water bath whose temperature was maintained to better than ±0.01 K. A Sartorius R120S balance with a precision of ±0.0001 g was used for mass measurements of liquid mixtures. The empty pycnometer was weighed several times until reproducibility was attained within ±0.0001 g. The densities of water were measured using this pycnometer, and these values were found to be in agreement with the literature.[6] The density values were reproducible within ±0.0002 g·cm^{-3}.

The viscosities of binary solutions were measured by Schott viscometers over the temperature range (303.15 to 343.15) K. The viscometer was submerged in a thermostatic bath which was controlled to better than ±0.01 K. The thermal equilibrium was attained within 30 min. An electronic stopwatch with an accuracy of 0.01 s was used to measure the efflux times of solutions. Four sets of readings were taken for the measurement of flow time, and the arithmetic mean value was taken as a reading for calculations. The accuracy of viscosity measurements is estimated to be ±1.0%.

The surface tensions were measured by the Plate (Wilhelmy) method by a dynamic contact angle analyzer (DCA) manufactured by Cahn Instruments. The operation and analysis were automatically controlled by the external computer, which is connected to the DCA. The description and dimensions of the plate have been given elsewhere.[5] To control the temperature of the sample within ±0.01 K, a bath circulator was used. The instrument was calibrated with spectroscopic-grade water, and the values were found to be in agreement with the literature.[6] The accuracy of the instrument is ±0.01 mN/m.

The refractive indices were measured with the precision Abbe refractometer 3T (Atago Co.). An external bath circulator was used to control the experimental temperature within ±0.01 K. The refractometer was calibrated with spectroscopic-grade water, and the resulting test values were found to be in close agreement with literature values.[6]

* To whom correspondence should be addressed. E-mail: hlee@mail.kaist.ac.kr.

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Table 1. Densities for Triisopropanolamine + Water

	ρ/g·cm^{-3} at the following mass % TIPA values				
T/K	5	10	15	20	25
303.15	0.9974	0.9989	1.0005	1.0022	1.0040
313.15	0.9934	0.9949	0.9964	0.9983	0.9998
323.15	0.9893	0.9908	0.9920	0.9935	0.9948
333.15	0.9844	0.9854	0.9869	0.9882	0.9893
343.15	0.9791	0.9806	0.9816	0.9831	0.9842

Table 2. Values of Regressed Coefficients Determined from Eq 1

		A_i	B_i	C_i	AAD/%
ρ/g·cm^{-3}	$i = 0$	0.85×10^3	0.13×10^1	-0.27×10^{-2}	0.01
	$i = 1$	0.40×10^1	-0.22×10^{-1}	0.34×10^{-4}	
	$i = 2$	-0.16×10^{-1}	0.15×10^{-3}	-0.31×10^{-6}	
η/mPa·s	$i = 0$	0.19×10^2	-0.99×10^{-1}	0.14×10^{-3}	0.91
	$i = 1$	0.39×10^2	-0.24	0.38×10^{-3}	
	$i = 2$	0.75×10^3	-0.42×10^1	0.59×10^{-2}	
σ/mN·m^{-1}	$i = 0$	0.11×10^3	0.85	-0.39×10^{-1}	0.40
	$i = 1$	-0.18	-0.86×10^{-2}	0.18×10^{-3}	
	$i = 2$	-0.93×10^{-4}	0.99×10^{-5}	-0.72×10^{-7}	
n_D	$i = 0$	0.12×10^1	0.11×10^{-2}	-0.20×10^{-5}	0.03
	$i = 1$	0.20×10^{-1}	-0.12×10^{-3}	0.18×10^{-6}	
	$i = 2$	-0.52×10^{-3}	0.32×10^{-5}	-0.49×10^{-8}	

Every measurement was performed three times with a reproducibility of $\pm 10^{-4}$.

Results and Discussion

The density, refractive index, viscosity, and surface tension data of the aqueous triisopropanolamine binary mixtures were measured at five different mass percentages, 5.0, 10.0, 15.0, 20.0, and 25.0. The results for all the properties over the temperature range (303.15 to 343.15) K are presented in Tables 1−5.

Density. The density values increased with increase in the mass percentage of triisopropanolamine. The densities of the mixtures decreased linearly with increase in temperature. The density values for 10 and 20 mass % aqueous triisopropanolamine solutions are in good agreement with the literature.[7] The measured densities of the binary mixtures are presented in Table 1. The data were regressed using the following polynomial equation:

$$\rho/\text{g·cm}^{-3} \text{ or } \eta/\text{mPa·s or } \sigma/\text{mN·m}^{-1} \text{ or } n_D = \sum_{i=0}^{2}[A_i x^i + B_i x^i (T/\text{K}) + C_i x^i (T/\text{K})^2] \quad (1)$$

where x is the mass fraction of TIPA. Each set of the determined parameters and average absolute deviations (AADs) between measured and calculated values is presented in Table 2. The average absolute deviations were found to be less than 0.01% for density. Average absolute deviation is calculated from the following equation:

$$\text{AAD} = \sum_{i=1}^{N} \frac{\left[\dfrac{P_{exp} - P_{cal}}{P_{exp}}\right]}{N} \quad (2)$$

where P_{exp} = experimental values, P_{cal} = calculated values, and N = number of points.

Viscosity. The viscosity values increased with increase in mass percentage of the triisopropanolamine. However, the viscosity decreased with increasing temperature. The measured viscosities of TIPA + H_2O are presented in Table 3. The results were regressed using eq 1. Parameters and average absolute deviations (AADs) between the measured and calculated values are given in Table 2. The maximum deviation was found to be less than 0.91% for viscosities.

Table 3. Viscosities for Triisopropanolamine + Water

	η/mPa·s at the following mass % TIPA values				
T/K	5	10	15	20	25
303.15	0.973	1.144	1.439	1.832	2.302
313.15	0.778	0.938	1.115	1.395	1.798
323.15	0.642	0.762	0.897	1.092	1.355
333.15	0.542	0.634	0.738	0.885	1.060
343.15	0.464	0.537	0.617	0.740	0.886

Table 4. Refractive Indices for Triisopropanolamine + Water

	n_D at the following mass % TIPA values				
T/K	5	10	15	20	25
303.15	1.341	1.348	1.355	1.361	1.370
313.15	1.339	1.347	1.354	1.360	1.369
323.15	1.338	1.345	1.352	1.358	1.367
333.15	1.335	1.343	1.349	1.357	1.365
343.15	1.333	1.341	1.348	1.355	1.364

Table 5. Surface Tensions for Triisopropanolamine + Water

	σ/mN·m^{-1} at the following mass % TIPA values				
T/K	5	10	15	20	25
303.15	49.99	46.25	43.33	40.71	38.55
313.15	47.59	43.77	41.13	38.50	36.42
323.15	45.13	41.22	38.29	36.40	34.21
333.15	42.79	38.72	36.00	34.19	32.11
343.15	40.29	36.22	33.59	32.06	30.01

Refractive Index. The refractive indices linearly decrease with increase in temperature and increase with increase in mass percentage of the triisopropanolamine. The measured values of refractive indices of aqueous TIPA solutions are presented in Table 4. The results were regressed using eq 1. Each set of the parameters and average absolute deviations (AADs) between the measured and calculated values is also presented in Table 2. The values for maximum deviations were found to be less than 0.03%.

Surface Tension. The surface tension values linearly decreased with increase in temperature and also decreased with increase in mass percentages of the triisopropanolamine. The measured surface tensions of TIPA + H_2O are presented in Table 5. The data were regressed using the polynomial equation (eq 1). Each set of the parameters and average absolute deviations (AADs) between measured and calculated values is also presented in Table 2. Maximum deviations were found to be less than 0.4%.

Conclusion

Physical and transport properties such as density, viscosity, refractive index, and surface tension of aqueous triisopropanolamine solutions were measured at (303.15, 313.15, 323.15, 333.15, and 343.15) K with TIPA concentrations of (5, 10, 15, 20, and 25) mass %. The measured physical properties were correlated by polynomial equations, and correlation parameters were obtained. Measured and calculated values agreed well within 0.01% for density, 0.91% for viscosity, 0.03% for refractive index, and 0.4% for surface tension in AADs.

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