Surface Tension of Aqueous Binary Mixtures of 1-Amino-2-Propanol and 3-Amino-1-Propanol, and Aqueous Ternary Mixtures of These Amines with Diethanolamine, Triethanolamine, and 2-Amino-2-methyl-1-propanol from (298.15 to 323.15) K

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The surface tension of aqueous binary solutions of 1-amino-2-propanol and 3-amino-1-propanol and aqueous ternary solutions of these amines with diethanolamine, triethanolamine, and 2-amino-2-methyl-1-propanol was measured at temperatures from 298.15 K to 323.15 K. For binary mixtures, the concentration range was 0−100 mass percent alkanolamine, and for ternary mixtures, the concentration range for each amine was 0−50 mass percent. The experimental values for binary mixtures were correlated with mole fraction by an empirical equation (the maximum deviation was in both cases always less than 0.2%).

Introduction

Absorption accompanied with the chemical reaction is a method usually employed for the removal of acid gases (CO_2 or SH_2) from gaseous streams[1] of industrial origin or from polluted atmosphere. The main objective of these processes is to minimize the environmental pollution and, specifically, the greenhouse effect. In particular, aqueous solutions of several amines are used to determine interfacial areas in gas−liquid contactors[2] and 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[3,4] or two-solute solutions[5,6] or with sterically hindered amines,[7] which leads to a considerable improvement of absorption rate and great savings of energy.

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 processes and the gas−liquid interfacial area. In addition, to calculate these parameters, certain physical properties of the liquid phase must be known: density, kinematic viscosity, or surface tension. Sometimes the literature covers these needs,[8] but often few surface tension data have been reported in systematic studies with the concentration and temperature for the systems of interest in gas−liquid mass transfer processes.[9]

As a previous experimental works continuation on binary and ternary aqueous solutions of alkanolamines,[10−12] this paper reports measurements of surface tension of binary aqueous solutions of 3-amino-1-propanol (AP) and 1-amino-2-propanol (MIPA) and ternary aqueous mixtures of these amines with diethanolamine (DEA), triethanolamine (TEA), or 2-amino-2-methyl-1-propanol (AMP) at temperatures of 298.15 K to 323.15 K. The total amine concentration for the ternary mixtures was held constant at 50 mass percent, and AP (or MIPA)/(DEA, TEA, or AMP) mass percent ratio was varied from 0/50 to 50/0, in 10 mass percent increments.

Experimental Section

AP (>99% pure), MIPA (>99% pure), AMP (>98% pure), DEA (>98% pure), and TEA (>98% pure) were Merck products. Water used as solvent was distilled and deionized. All solutions were prepared by weighing the solutes and solvent on a Mettler AT 261 balance to whiting ±0.01 mg. For binary mixtures, the values of the mole fraction, x_A, correspond to 0−100 mass percent, at 10% intervals, of amine. For ternary mixtures, the different mol fraction ratios correspond to 0/50, 10/40, 20/30, 30/20, 40/10, and 50/0 AP (or MIPA)/ (DEA, TEA or AMP) mass percent ratios, respectively.

The surface tension was determined at 5 K intervals, between 298.15 K and 323.15 K, using a KRÜSS Drop Shape Analysis System G10/DSA10, which employs the pendant drop method.[13] It is built around a rapid video capture of images and automatic image analysis. Measurements are made by observing the drop shape of a fluid which reveals information about the fluid itself about the surrounding media. The emergent drop image is captured easily, and it is sent to the video recording system or to the computer. Finally, the Laplace-Young equation is used by the PDA program to obtain the *xy* profile of the drop and the interfacial tension.

The surface tension was measured with an uncertainty of ±0.02 $mN\cdot m^{-1}$, and the temperature was controlled, using a Polyscience 9010 bath, with a precision of ±0.01 K. Each surface tension value reported was an average of 5−10 measurements, where the maximum deviations from the average value were always less than 0.05%.

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Table 1. Surface Tension (σ) of 1-Amino-2-propanol + Water System at Different Mol Fractions of Amine (x_A)

	T/K					
x_A	298.15	303.15	308.15	313.15	318.15	323.15
	σ/mN m^{-1}					
0.0000	72.01	71.21	70.42	69.52	68.84	67.92
0.0125	66.34	64.98	63.65	62.50	61.31	59.82
0.0259	62.20	60.80	59.33	58.04	56.69	55.27
0.0565	56.95	55.45	53.95	52.60	51.20	49.75
0.0931	53.59	52.06	50.57	49.30	47.94	46.58
0.1378	51.07	49.59	48.24	46.95	45.63	44.33
0.1933	49.00	47.59	46.30	45.05	43.76	42.51
0.2644	47.18	45.81	44.60	43.34	42.10	40.88
0.3586	45.40	44.01	42.84	41.64	40.42	39.19
0.4894	43.43	42.08	40.94	39.70	38.51	37.30
0.6832	40.97	39.63	38.46	37.26	36.08	34.85
1.0000	37.38	36.03	34.89	33.68	32.49	31.28

Table 2. Surface Tension (σ) of 3-Amino-1-propanol + Water System at Different Mol Fractions of Amine (x_A)

	T/K					
x_A	298.15	303.15	308.15	313.15	318.15	323.15
	σ/mN m^{-1}					
0.0000	72.01	71.21	70.42	69.52	68.84	67.92
0.0125	69.62	68.52	67.59	66.54	65.47	64.41
0.0259	67.45	66.16	65.20	63.97	62.78	61.62
0.0565	63.69	62.27	61.19	59.90	58.66	57.38
0.0931	60.50	59.12	58.03	56.80	55.50	54.31
0.1378	57.76	56.46	55.36	54.21	53.00	51.88
0.1933	55.29	54.14	53.10	52.00	50.87	49.80
0.2644	53.08	52.01	51.03	50.05	48.97	47.88
0.3586	51.01	50.01	49.05	48.12	47.05	46.00
0.4894	48.89	47.93	46.98	46.08	45.04	44.03
0.6832	46.65	45.67	44.65	43.67	42.63	41.61
1.0000	43.90	42.77	41.61	40.48	39.33	38.16

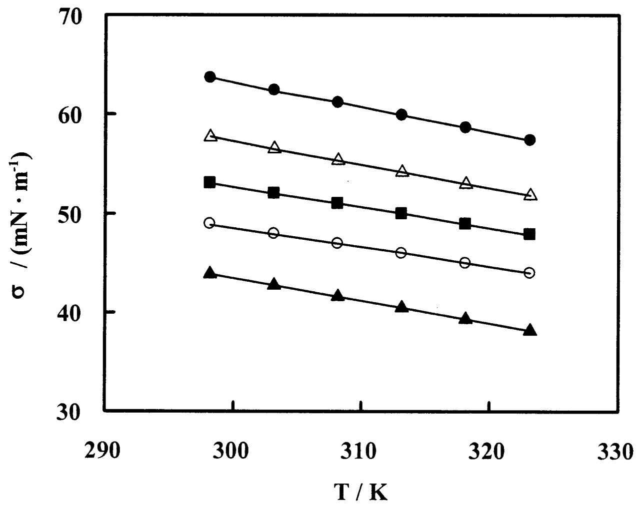

Figure 1. Surface tension of 3-amino-1-propanol + water as a function of temperature at different mole fractions of amine: ●, $x_A = 0.0565$; △, $x_A = 0.1378$; ■, $x_A = 0.2644$; ○, $x_A = 0.4894$; ▲, $x_A = 1.0000$.

On the other hand, the surface tensions for the (AP or MIPA)/(DEA, TEA, or AMP) mass percent ratio of the 0/50 have been determined in previous papers[10,11] using a Prolabo tensiometer, which employs the Wilhemy plate principle.[14]

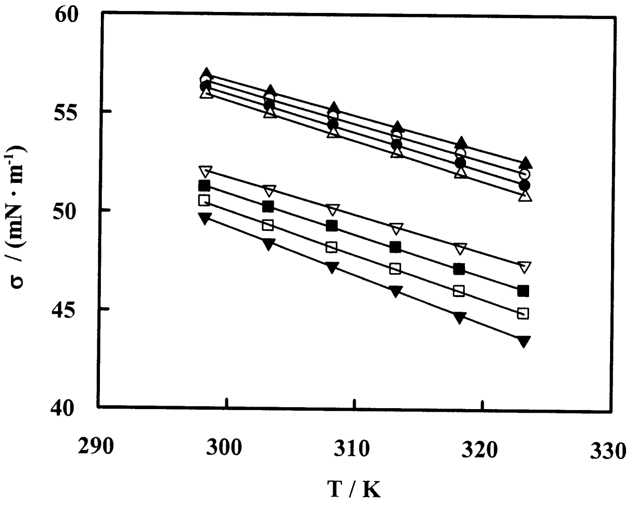

Figure 2. Surface tension of two ternary systems as a function of temperature at different mass percent ratios: ▲, 10% AP/40% DEA; ○, 20% AP/30% DEA; ●, 30% AP/20% DEA; △, 40% AP/10% DEA; ▽, 10% MIPA/40% TEA; ■, 20% MIPA/30% TEA; □, 30% MIPA/20% TEA; ▼, 40% MIPA/10% TEA.

Table 3. Surface Tension (σ) of 1-Amino-2-propanol (MIPA) + Diethanolamine (DEA) + Water

	mol fraction of MIPA/mol fraction of DEA					
T/K	0.0000/ 0.1463	0.0404/ 0.1157	0.0800/ 0.0858	0.1186/ 0.0566	0.1564/ 0.0280	0.1933/ 0.0000
	σ/mN m^{-1}					
298.15	57.20	55.54	53.91	52.28	50.62	48.98
303.15	56.42	54.66	52.93	51.18	49.40	47.59
308.15	55.62	53.70	51.92	50.06	48.18	46.30
313.15	54.71	52.79	50.89	48.97	46.98	45.05
318.15	54.01	51.82	49.86	47.84	45.81	43.76
323.15	53.07	50.88	48.85	46.74	44.61	42.50

Table 4. Surface Tension (σ) of 1-Amino-2-propanol (MIPA) + Triethanolamine (TEA) + Water

	mol fraction of MIPA/mol fraction of TEA					
T/K	0.0000/ 0.1077	0.0419/ 0.0843	0.0821/ 0.0620	0.1206/ 0.0405	0.1577/ 0.0198	0.1933/ 0.0000
	σ/mN m^{-1}					
298.15	52.88	52.06	51.24	50.50	49.70	48.98
303.15	52.08	51.12	50.22	49.28	48.42	47.59
308.15	51.29	50.20	49.28	48.20	47.28	46.30
313.15	50.37	49.28	48.24	47.14	46.10	45.05
318.15	49.68	48.30	47.16	46.04	44.80	43.76
323.15	48.78	47.40	46.08	44.94	43.62	42.50

Table 5. Surface Tension (σ) of 1-Amino-2-propanol (MIPA) + 2-Amino-2-methyl-1-propanol (AMP) + Water

	mol fraction of MIPA/mol fraction of AMP					
T/K	0.0000/ 0.1682	0.0396/ 0.1337	0.0788/ 0.0997	0.1174/ 0.0661	0.1556/ 0.0328	0.1933/ 0.0000
	σ/mN m^{-1}					
298.15	39.58	41.57	43.49	45.33	47.25	48.98
303.15	38.98	40.84	42.65	44.36	46.10	47.59
308.15	38.37	40.10	41.84	43.43	44.96	46.30
313.15	37.76	39.41	41.02	42.45	43.82	45.05
318.15	37.14	38.69	40.20	41.51	42.68	43.76
323.15	36.50	37.93	39.39	40.53	41.53	42.50

Results and Discussion

The experimental results are reported in Tables 1 and 2 for binary systems and in Tables 3 to 8 for ternary aqueous solutions. In all systems studied, the surface tension decreased linearly with increasing temperature for any given concentration or mol fraction ratio of amine (see Figures 1 and 2), and for each temperature, the surface tension of binary systems decreased as the alkanolamine concentration increased. This trend is nonlinear, the change in surface tension caused by a given change in alkanolamine concentration being larger at low concentra-

Table 6. Surface Tension (σ) of 3-Amino-1-propanol (AP) + Diethanolamine (DEA) + Water

	mol fraction of AP/mol fraction of DEA					
T/K	0.0000/ 0.1463	0.0404/ 0.1157	0.0800/ 0.0858	0.1186/ 0.0566	0.1564/ 0.0280	0.1933/ 0.0000
	σ/mN m^{-1}					
298.15	57.20	56.89	56.57	56.25	55.92	55.29
303.15	56.42	56.06	55.69	55.33	54.96	54.14
308.15	55.62	55.22	54.81	54.38	53.97	53.10
313.15	54.71	54.28	53.84	53.41	52.99	52.00
318.15	54.01	53.51	52.99	52.51	52.00	50.87
323.15	53.07	52.52	51.97	51.41	50.86	49.80

Table 7. Surface Tension (σ) of 3-Amino-1-propanol (AP) + Triethanolamine (TEA) + Water

	mol fraction of AP/mol fraction of TEA					
T/K	0.0000/ 0.1077	0.0419/ 0.0843	0.0821/ 0.0620	0.1206/ 0.0405	0.1577/ 0.0198	0.1933/ 0.0000
	σ/mN m^{-1}					
298.15	52.88	53.36	53.84	54.33	54.81	55.29
303.15	52.08	52.50	52.91	53.32	53.73	54.14
308.15	51.29	51.63	52.01	52.37	52.74	53.10
313.15	50.37	50.71	51.06	51.35	51.68	52.00
318.15	49.68	49.90	50.16	50.40	50.64	50.87
323.15	48.78	48.98	49.19	49.41	49.60	49.80

Table 8. Surface Tension (σ) of 3-Amino-1-propanol (AP) + 2-Amino-2-methyl-1-propanol (AMP) + Water

	mol fraction of AP/mol fraction of AMP					
T/K	0.0000/ 0.1682	0.0396/ 0.1337	0.0788/ 0.0997	0.1174/ 0.0661	0.1556/ 0.0328	0.1933/ 0.0000
	σ/mN m^{-1}					
298.15	39.58	42.92	46.06	48.95	52.19	55.29
303.15	38.98	42.25	45.37	48.07	51.20	54.14
308.15	38.37	41.57	44.58	47.24	50.15	53.10
313.15	37.76	40.91	43.84	46.40	49.17	52.00
318.15	37.14	40.25	43.10	45.54	48.21	50.87
323.15	36.50	39.56	42.32	44.61	47.25	49.80

Table 9. Parameters of Equation 1 for the 1-Amino-2-propanol and 3-Amino-1-propanol Concentration Dependence of the Surface Tension of the Aqueous Binary Mixtures

	1-amino-2-propanol + water		3-amino-1-propanol + water	
T/K	A	B	A	B
298.15	0.6880	0.9572	0.7275	0.8885
303.15	0.6906	0.9602	0.7068	0.9050
305.15	0.6929	0.9638	0.6929	0.9113
313.15	0.6944	0.9654	0.6737	0.9210
318.15	0.6972	0.9681	0.6656	0.9300
323.15	0.6982	0.9700	0.6557	0.9351

tions than at high concentrations. We fit the equation

$$\frac{\sigma_W - \sigma}{\sigma_W - \sigma_A} = \left(1 + \frac{Ax_W}{1 - Bx_W}\right)x_A \tag{1}$$

to the data for each solute (where σ_w and σ_A represents the surface tensions of the pure water and pure alkanolamine, respectively, and x_W and x_A represents the mole fractions of water and alkanolamine). In this equation, A and B are two fitted parameters whose values are listed in Table 9. The dependence of A and B on temperature was expressed by an empirical equation of the form

$$F = \sum_{i=0}^{2} F_i (T/K)^i \tag{2}$$

where $F = A$ or B parameters, and F_i are the adjustable coefficients (A_0, A_1, A_2, B_0, B_1, or B_2) whose values are listed in Table 10 for each binary system. The relative deviation between experimental and estimated surface tensions was not greater than ±0.2%. The comparison between the experimental and calculated surface tensions for one of the studied binary mixtures is graphically shown in Figure 3.

The surface tension deviation (δ_σ) is defined as the difference between the surface tension of the mixture and

Table 10. Parameters F_i in Equation 2 for 1-Amino-2-propanol + Water and 3-Amino-1-propanol + Water Binary Mixtures

	1-amino-2-propanol + water	3-amino-1-propanol + water
A_0	0.151	6.935
A_1/K^{-1}	3.083	−37.383
A_2/K^{-2}	−4.300	55.550
B_0	0.161	−2.231
$B_1 \times 10^3$ /K^{-1}	4.661	22.306
$B_2 \times 10^6$ /K^{-2}	−6.679	−32.986

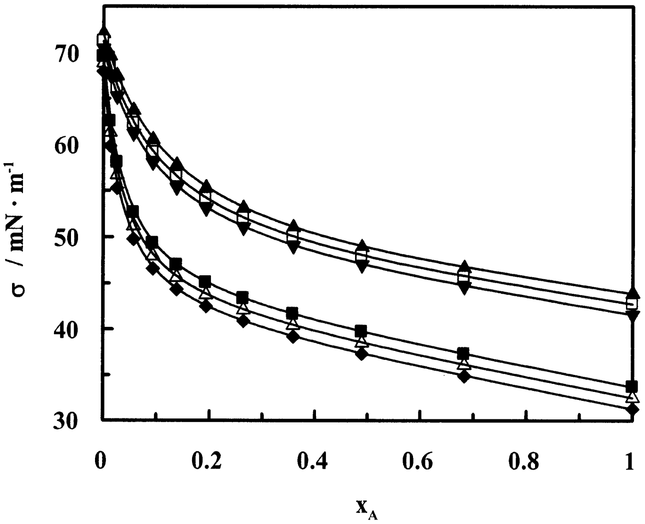

Figure 3. Surface tension of binary aqueous solutions, σ, plotted against the mole fraction of amine, x_A: ▲, AP + water, 298.15 K; □, AP + water, 303.15 K; ▼, AP + water, 308.15 K; ■, MIPA + water, 323.15 K; △, MIPA + water, 318.15 K; ◆, MIPA + water, 323.15 K; —, calculated from eq 2.

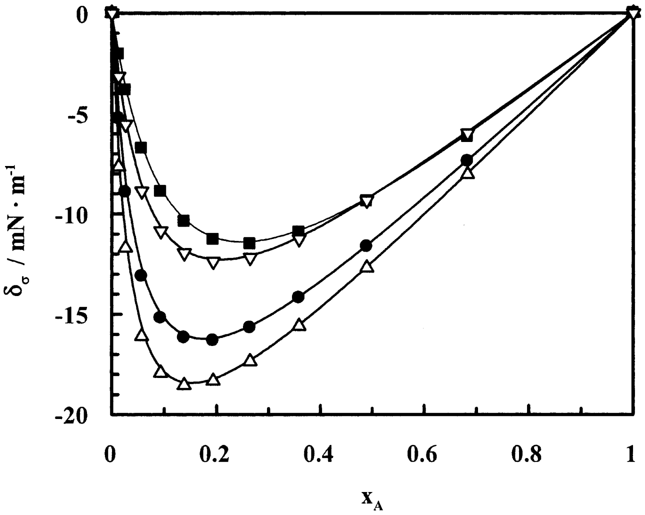

Figure 4. Surface tension deviation, δ_σ, as a function of the mole fraction of amine, x_A: ■, 1-amino-2-propanol, 298.15 K; ▽, 1-amino-2-propanol, 323.15 K; ●, 3-amino-1-propanol, 298.15 K; △, 3-amino-1-propanol, 323.15 K.

that expected on the basis of a mole fraction average

$$\delta_\sigma = \sigma - (\sigma_W x_W + \sigma_A x_A) \tag{3}$$

Plotting δ_σ against the mole fraction of the amine (Figure 4) shows that the deviation from a mole fraction average is larger for the 3-amino-1-propanol than for the 1-amino-2-propanol.

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