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Surface Tension of Aqueous Solutions of Diethanolamine and Triethanolamine from 25 °C to 50 °C

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The surface tension of aqueous solutions of diethanolamine and triethanolamine was measured over the entire concentration range at temperatures of 25 °C to 50 °C. The experimental values were correlated with temperature and with mole fraction. The maximum deviation was in both cases always less than 0.5%.

Introduction

Aqueous solutions of alkanolamines such as monoethanolamine (MEA), diethanolamine (DEA), triethanolamine (TEA), *N*-methyldiethanolamine (MDEA), and 2-amino-2-methyl-1-propanol (AMP) are good solvents for the removal of acid gases such CO_2 and H_2S from the gas streams of many processes in the natural gas, ammonia synthesis, and some chemical industries (Astarita et al., 1983). Aqueous solutions of a tertiary amine like MDEA or TEA are used for selective removal of H_2S in the presence of CO_2, while DEA is a common solvent for removal of CO_2 (Hagewiesche et al., 1995; Rangwala et al., 1992). The reaction between and aqueous solutions of alkanolamines has also been used for the determination of interfacial areas in a mechanically agitated reactor and a bubble column (Oyervaar et al., 1990).

The physical properties of aqueous solutions of these alkanolamines, such as surface tension, are important for the design of acid gas treatment equipment and for interpreting other physicochemical properties of this system such as the reaction kinetics of CO_2 with aqueous amine solutions. The objective of this work was to measure the surface tension of the binary aqueous solutions of DEA and of TEA over the entire concentration range at temperatures of 25 °C to 50 °C.

Experimental Section

Aqueous solutions of diethanolamine and triethanolamine were prepared with distilled-deionized water. Alkanolamines were Merck products of nominal purity >98% for the DEA and >99% for the TEA. All the solutions were prepared by mass with deviations of less than 0.3% from the desired concentration. The values of the mole fraction, , correspond for all mixtures to 0−100 mass %, at 10 mass % intervals, of DEA and TEA.

Surface tension was determined at 5 deg intervals, between 25 °C and 50 °C, using a Traube stalagmometer and a Prolabo tensiometer, which employs the Wilhemy plate principle (Lin et al., 1990; Van der Bogaert and Joos, 1980). The detailed experimental procedure has been described elsewhere (Vázquez et al., 1995a, 1995b). In general, each surface tension value reported was an average of 5 to 10 measurements, where the maximum deviations from the average value were always less than 0.4%. The precision of the temperature control was ±0.05 deg and the accuracy of the measurements was ±0.05 mN m^{-1}.

Table 1. Surface Tension of Diethanolamine (A) + Water (B)

	σ/mN m^{-1} at t/°C					
x_A	25	30	35	40	45	50
0.000	72.01	71.21	70.42	69.52	68.84	67.92
0.019	66.70	65.89	65.10	64.19	63.49	62.56
0.041	63.25	62.46	61.65	60.74	60.04	59.10
0.068	60.75	59.95	59.15	58.25	57.54	56.60
0.102	58.82	58.03	57.23	56.32	55.61	54.68
0.146	57.20	56.42	55.62	54.71	54.01	53.07
0.204	55.75	54.96	54.17	53.26	52.56	51.63
0.285	54.32	53.55	52.74	51.83	51.13	50.19
0.407	52.72	51.95	51.14	50.24	49.54	48.61
0.606	50.65	49.89	49.10	48.18	47.48	46.55
1.000	47.21	46.46	45.66	44.75	44.05	43.12

Table 2. Surface Tension of Triethanolamine (A) + Water (B)

	σ/mN m^{-1} at t/°C					
x_A	25	30	35	40	45	50
0.000	72.01	71.21	70.42	69.52	68.84	67.92
0.013	65.85	65.05	64.26	63.35	62.67	61.74
0.029	61.32	60.52	59.73	58.82	58.13	57.21
0.049	57.80	57.00	56.20	55.31	54.62	53.69
0.074	55.10	54.30	53.51	52.61	51.91	50.99
0.108	52.88	52.08	51.29	50.37	49.68	48.76
0.153	51.03	50.23	49.44	48.53	47.84	46.92
0.220	49.48	48.68	47.89	46.99	46.30	45.37
0.326	48.16	47.36	46.57	45.66	44.98	44.05
0.521	47.00	46.21	45.42	44.52	43.83	42.90
1.000	45.95	45.16	44.38	43.48	42.80	41.88

Table 3. Surface Tension Parameters K_1 and K_2 (Eq 1) for Aqueous Alkanolamine Mixtures

organic component (A)	x_A	K_1	K_2	x_A	K_1	K_2
diethanolamine	0.000	76.0114	0.1609	0.204	55.1209	0.1634
	0.019	69.8596	0.1613	0.285	53.5757	0.1637
	0.041	65.3409	0.1618	0.407	52.2662	0.1640
	0.068	61.8319	0.1622	0.606	51.1533	0.1644
	0.102	59.1505	0.1625	1.000	50.0795	0.1648
	0.146	56.9394	0.1629			
triethanolamine	0.000	76.0114	0.1609	0.153	59.7938	0.1625
	0.013	70.6786	0.1612	0.220	58.3841	0.1627
	0.029	67.2534	0.1614	0.326	56.8157	0.1629
	0.049	64.7652	0.1617	0.521	54.7309	0.1630
	0.074	62.8468	0.1620	1.000	51.3248	0.1633
	0.108	61.2490	0.1622			

Results and Discussion

Tables 1 and 2 list the measured surface tensions of DEA + water and TEA + water of various mole fractions at each temperature. In the systems studied surface tension decreased with increasing temperature for any given mole

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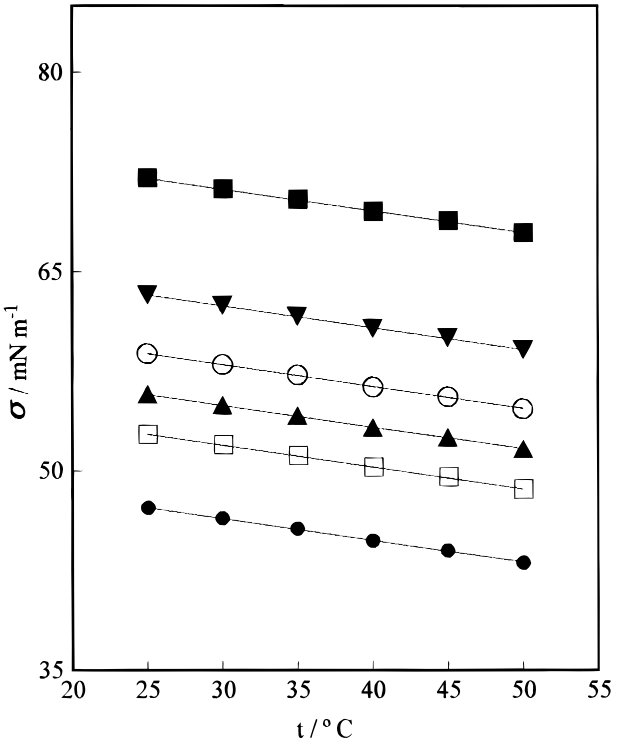

Figure 1. Surface tension of diethanolamine (A) + water (B) as a function of temperature at different mole fractions of DEA: (■) water; (▼) x_A = 0.041; (○) x_A = 0.102; (▲) x_A = 0.204; (□) x_A = 0.407; (●) x_A = 1.000; (—) eq 1.

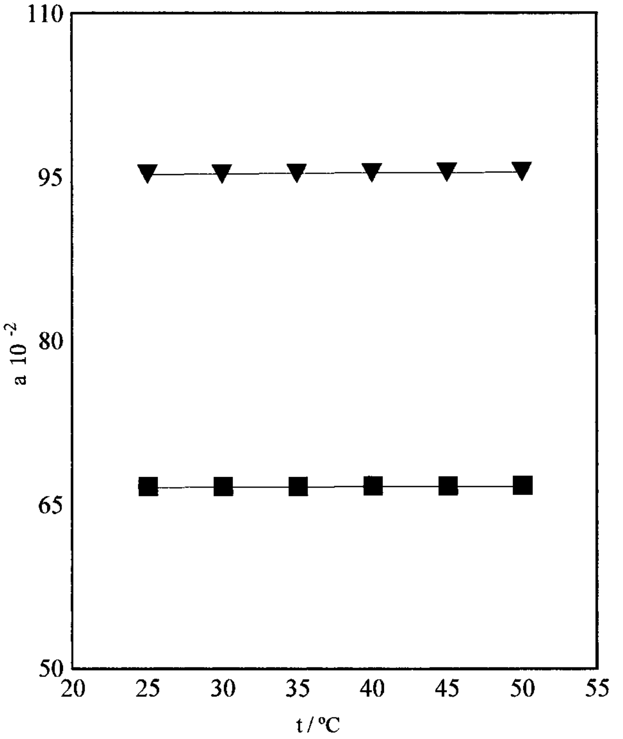

Figure 2. Fitted parameter *a* (eq 2) as a function of temperature: (■) diethanolamine; (▼) triethanolamine.

fraction of alkanolamine. The surface tensions of the pure components can be correlated with temperature by fitting the following linear expression (Jasper, 1972).

$$\sigma/\mathrm{mN{\cdot}m^{-1}} = K_1 - K_2 t/°\mathrm{C} \qquad (1)$$

Equation 1 also fitted the data of Tables 1 and 2 for each concentration, with deviations less than 0.5%. Figure 1 shows the results for DEA + water as an example. The fitted values of K_1 and K_2 are listed in Table 3.

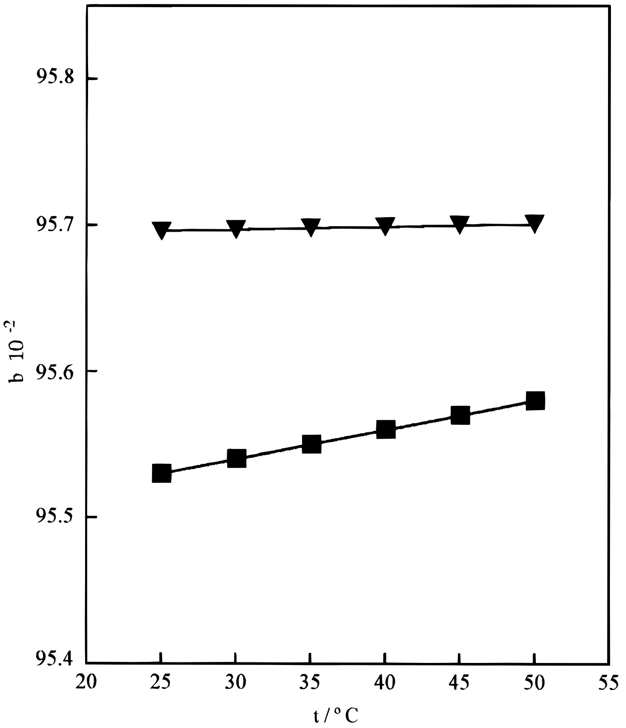

Figure 3. Fitted parameter *b* (eq 2) as a function of temperature: (■) diethanolamine; (▼) triethanolamine.

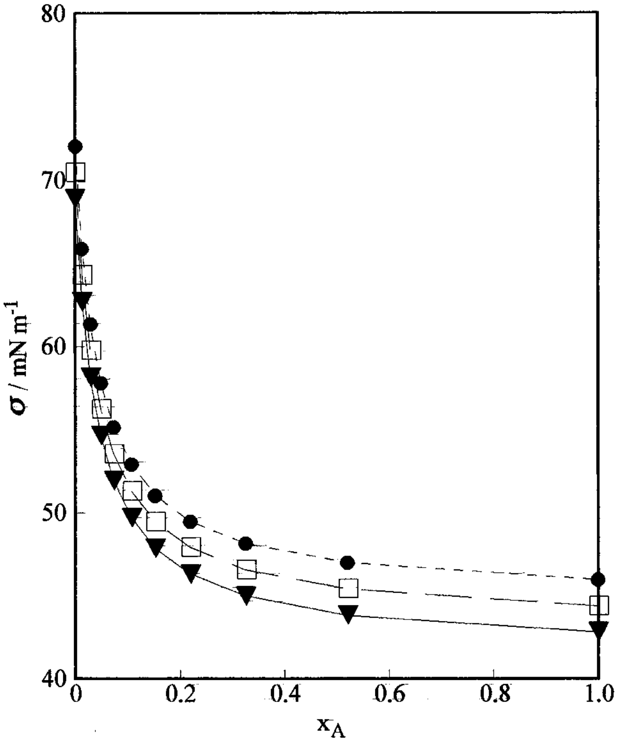

Figure 4. Surface tension of triethanolamine + water plotted against the mole fraction of alkanolamine, x_A: (●) experimental, 25 °C; (---) calculated, 25 °C; (□) experimental, 35 °C; (− − −) calculated, 35 °C; (▼) experimental, 45 °C; (—) calculated, 45 °C.

For a given temperature, the surface tension of the mixtures studied 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 concentrations than at high concentrations. Fitting the equation

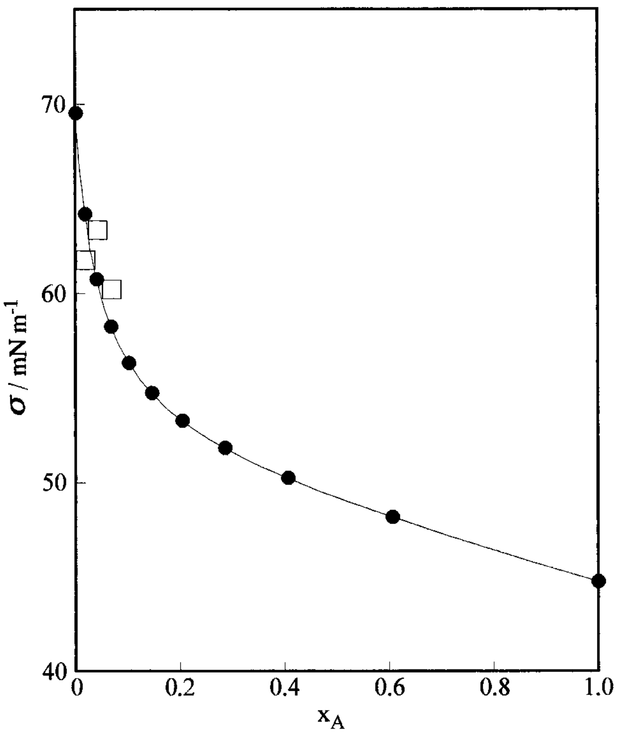

Figure 5. Surface tension of diethanolamine + water, at 40 °C, plotted against the mole fraction of alkanolamine, x_A: (●) experimental; (□) Rinker et al., 1994.

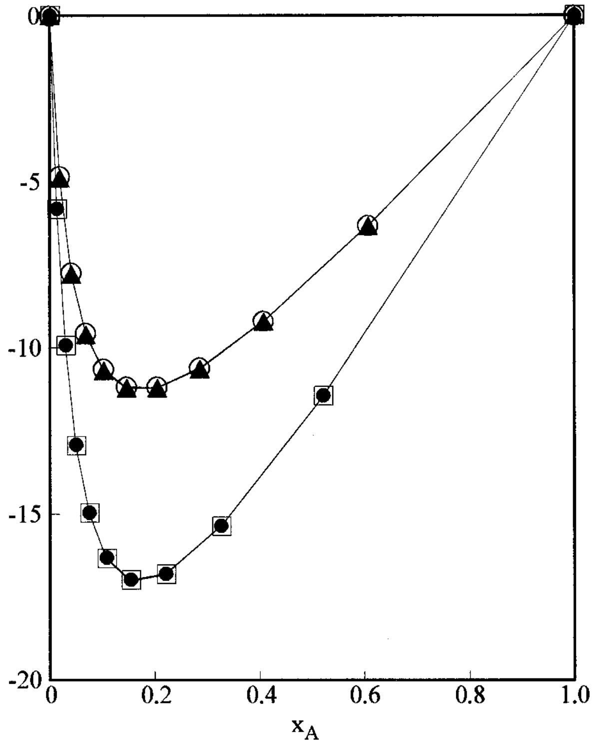

Figure 6. Surface tension deviation, $\delta\sigma$, as a function of the mole fraction of alkanolamine, x_A: (○) diethanolamine, 25 °C; (▲) diethanolamine, 50 °C; (●) triethanolamine, 25 °C; (□) triethanolamine, 50 °C; (—) calculated from eqs 2 and 3.

$$\frac{\sigma - \sigma_w}{\sigma_w - \sigma_A} = \left(1 + \frac{a x_w}{1 - b x_w}\right) x_A \qquad (2)$$

to the data for each solute (where σ_w and σ_A are the surface tensions of pure water and pure alkanolamine, respectively, and x_w and x_A are the mole fractions of water and alkanolamine). The values of the fitted parameters *a* and *b* in eq 2 are a linear function of the temperature for each alkanolamine (see Figures 2 and 3). Figure 4 shows, by way of example, the measured surface tensions for TEA + water in comparison with those calculated by means of eq 2. The deviations are less than 0.2% in all such plots.

In Figure 5 the values of surface tension for DEA + water at 40 °C reported in this paper were compared with experimental values obtained by other researchers (Rinker et al., 1994).

The surface tension deviation is defined as the difference between the surface tension of the mixture and those expected on the basis of a mole fraction average,

$$\delta\sigma = \sigma - (\sigma_w x_w + \sigma_A x_A) \qquad (3)$$

Plotting $\delta\sigma$ against the mole fraction of the amine (Figure 6) shows that the deviation from a mole fraction average is larger for the tertiary amine than for the secondary amine.

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