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Surface Tension of Binary Mixtures of Ethanol + Ethylene Glycol from 20 to 50 °C

Saeid Azizian* and Maryam Hemmati

Department of Chemistry, Faculty of Science, Bu-Ali Sina University, Hamadan, Iran

Surface tension data of binary mixtures of ethanol + ethylene glycol were measured over the entire concentration range at temperatures from 20 to 50 °C. The experimental values were correlated with temperature and with mole fraction. The values of the excess surface tension for these mixtures were also calculated.

Introduction

The surface tension of mixtures is an important physical property in mass transfer processes such as liquid−liquid extraction, gas absorption, distillation, and condensation. The surface tension is also a property that represents changes in molecular interaction and could thus be used as a means of interpreting behavior of binary mixtures.

The literature dealing with surface tension of binary mixtures is extensive, but the systems which involve alcohols are interesting,[1−3] because of their inherent nature of forming associations in the form of hydrogen bonds within themselves or with other components.

The objective of this work was to measure the surface tension of binary mixtures of ethanol + ethylene glycol over the entire concentration range at temperatures from 20 to 50 °C. The values of the excess surface tension for these binary mixtures have also been computed.

Experimental Section

Ethanol (99.8%) and ethylene glycol (99.5%) were Merck products and were used as received. All mixtures were prepared by mass in glass, stoppered flasks. The balance precision was $\pm 1 \times 10^{-4}$ g. The accuracy of the mole fractions was estimated to be within ±0.001. The surface tensions of the samples were measured by a ring-detachment method using a Kruss torsion balance. The platinum ring was thoroughly cleaned and flame-dried before each measurement. The torsion balance was calibrated with methanol. All solutions were thermostated with a precision of ±0.1 K using a Multi Temp III thermostat, and the temperature intervals between 20 and 50 °C were 5 °C. The system was not isolated from ambient moisture. Each value reported was an average of at least four measurements, where the reproducibility of replicate measurements on the same sample was within ±0.5%.

Results and Discussion

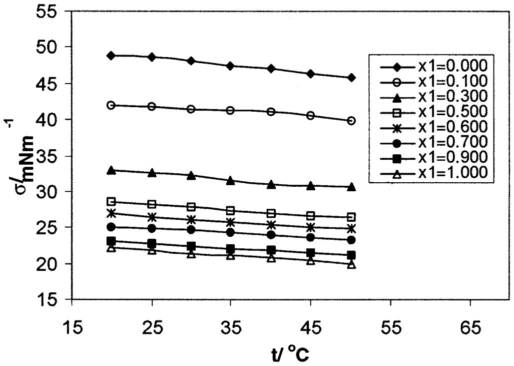

Figure 1. Surface tension of ethanol (1) + ethylene glycol (2) as a function of temperature at different mole fractions of ethanol (x_1).

Table 1. Surface Tension (σ/mN·m^{-1}) of Ethanol (1) + Ethylene Glycol (2)

	σ/mN·m^{-1} at the following t/°C						
x_1	20.0	25.0	30.0	35.0	40.0	45.0	50.0
0.000	48.9	48.6	48.1	47.5	47.1	46.4	45.9
0.100	42.0	41.8	41.4	41.2	41.0	40.6	39.8
0.300	32.9	32.7	32.2	31.6	31.1	30.8	30.7
0.500	28.5	28.3	27.8	27.4	27.0	26.7	26.5
0.600	26.9	26.4	26.1	25.8	25.4	25.0	24.8
0.700	25.0	24.9	24.7	24.4	24.0	23.6	23.2
0.900	23.1	22.68	22.33	22.05	21.8	21.55	21.1
1.000	22.3	21.8	21.4	21.1	20.8	20.5	20.0

Table 1 lists the measured surface tensions of ethanol + ethylene glycol mixtures of various concentrations at each temperature. In all systems studied, the surface tension, σ, decreased with increasing temperature at any mole fraction. The surface tensions of binary mixtures were correlated with temperature by the following linear expression,[4] proposed for the pure component:

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

Equation 1 also fitted the data of Table 1 for each concentration, with an average deviation of less than 1%. Figure 1 shows the results for ethanol and ethylene glycol. The fitted values of K_1 and K_2 are given in Table 2.

For a given temperature the surface tensions of all binary mixtures investigated here decreased with an increase of the ethanol mole fraction, which is listed in Table 1. This trend was nonlinear, with the change in surface tension caused by a given change in ethanol mole fraction being larger at low mole fractions than at high mole fractions. Connors and Wright[5] proposed an equation of the following form that has been used successfully in

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* To whom correspondence should be addressed. E-mail: sazizian@basu.ac.ir.

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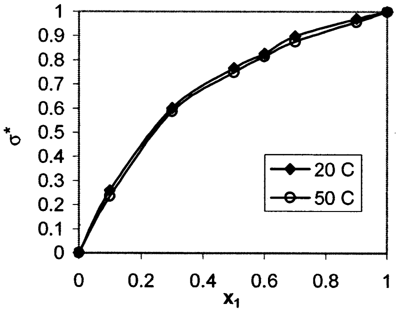

Figure 2. Dimensionless surface tension, σ^*, vs the mole fraction of ethanol (x_1) at various temperatures.

Table 2. Surface Tension Parameters K_1 and K_2 (Eq 1) for Ethanol (1) + Ethylene Glycol (2)

x_1	K_1	K_2
0.000	51.1000	0.1029
0.100	43.4643	0.0672
0.300	34.5893	0.0821
0.500	29.9571	0.0714
0.600	28.2214	0.0700
0.700	26.4321	0.0621
0.900	24.2846	0.0628
1.000	23.6536	0.0721

the chemical literature:[1−3,6]

$$\sigma^* = \frac{\sigma_2 - \sigma}{\sigma_2 - \sigma_1} = \frac{1 + ax_2}{1 - bx_2}x_1 \tag{2}$$

where σ_1 and σ_2 are the surface tensions of pure 1 and 2 and a and b are adjustable parameters. The dependent variable σ is the surface tension of the mixed solvent. This equation describes the effect of composition on the mixture surface tension. The dimensionless surface tension, σ^*, is a weak function of temperature over most of the concentration range. The σ^*-x_1 curve is shown in Figure 2 for temperatures of 20 °C and 50 °C. The relation between σ^* and x_1 (eq 2) is nonlinear, so for finding the values of the fitted parameters a and b in eq 2, we defined a simple method. By linearization of eq 2 we obtain:

$$\frac{x_1}{(\sigma^* - x_1)} = \frac{1}{ax_2} - \frac{b}{a} \tag{3}$$

The plot of $x_1/(\sigma^* - x_1)$ versus $1/x_2$ gives a straight line with slope equal to $1/a$ and intercept equal to $-b/a$. So the fitted parameters a and b were determined at each temperature from slope and intercept, respectively. These plots for ethanol + ethylene glycol at 20 °C and 50 °C are represented in Figure 3. The a and b values obtained at each temperature from plots such as Figure 3 are listed in Table 3. The values of the fitted parameters a and b in eq 2 or 3 are linear functions of temperature.

The excess surface tension, σ^E, is defined as the difference between the surface tension of the mixture, σ, and that expected on the basis of a mole fraction average

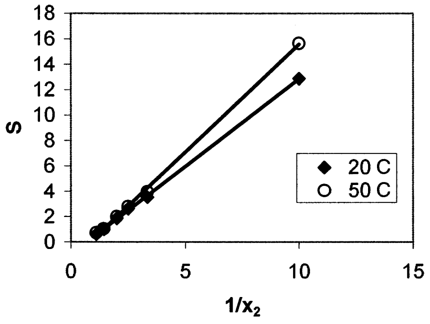

Figure 3. Plot of $S = x_1/(\sigma^* - x_1)$ vs $1/x_2$.

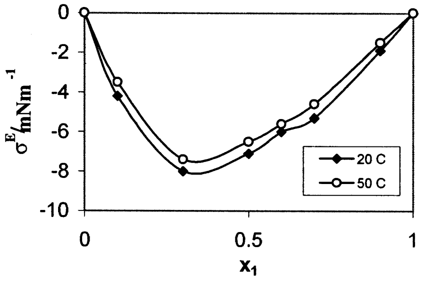

Figure 4. Plot of the excess surface tension, σ^E, vs mole fraction of ethanol, x_1, at 20 and 50 °C.

Table 3. Surface Tension Parameters *a* and *b* (Eqs 2 and 3) for Ethanol (1) + Ethylene Glycol (2)

t/°C	20.0	25.0	30.0	35.0	40.0	45.0	50.0
a	0.7257	0.6958	0.6746	0.6588	0.6378	0.6119	0.5898
b	0.6696	0.6771	0.6964	0.7132	0.7672	0.8102	0.8202

$$\sigma^E = \sigma - (\sigma_1 x_1 + \sigma_2 x_2) \tag{4}$$

The values of σ^E for various mole fractions of ethanol at 20 °C and 50 °C are shown in Figure 4. The mixtures of ethanol + ethylene glycol show a minimum in the σ^E value at 0.3 mole fraction of ethanol at various temperatures.

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