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Solubility of Ethane in Aqueous Solutions of 2-(2-Aminoethoxy)ethanol

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The solubility of ethane in (3.0 and 6.0) kmol·m^{-3} (30.5 and 59.5 mass %) solutions of 2-(2-aminoethoxy)ethanol has been measured over a range of temperatures from (298 to 398) K. Pressures varied between (93 and 13 380) kPa. The experimental data were modeled using a Henry's law approach, and the results are summarized in terms of salting-in ratios and Setchenow coefficients.

Introduction

Aqueous solutions of alkanolamines are commonly used in the hydrocarbon processing industry to remove acid gases (hydrogen sulfide and carbon dioxide) from raw hydrocarbon streams. The solubility of the light hydrocarbons in alkanolamine solutions is important, as the dissolved hydrocarbons are a loss to the process. The estimation of the solubility of hydrocarbons in the amine solution is necessary in the design of these processes. There is only a limited amount of solubility data for the light hydrocarbons in alkanolamine solutions. Lawson and Garst[1] measured the solubility of methane and ethane in monoethanolamine (MEA) and diethanolamine (DEA) solutions. Jou et al.[2] measured the solubility of methane and ethane in methyldiethanolamine (MDEA) solutions. One of the amines used in this process is 2-(2-aminoethoxy)ethanol, commonly called diglycolamine or DGA. It is a registered trademark of the Huntsman Corp. Jou et al.[3] measured the solubility of methane in two DGA solutions. Carroll and Mather[4] presented a model for the solubility of light hydrocarbons in aqueous alkanolamine solutions. This model will be used for the correlation of the data reported here.

Experimental Section

The apparatus and experimental technique that were used are similar to those described by Jou et al.[5] The equilibrium cell was mounted in an air bath. The temperature of the contents of the cell was measured by a calibrated iron−constantan thermocouple, and the pressure in the cell was measured by digital Heise gauges (0 to 10, 0 to 35) MPa. The uncertainty in the pressures was ± 0.1 % of full scale by comparison with a deadweight gauge. The experimental uncertainty in the temperature was ± 0.1 K by comparison with a platinum resistance thermometer. The ethane had a purity of 99 % and was obtained from Matheson. The diglycolamine (DGA, CAS No. 929-06-6) was obtained from Aldrich and had a purity of > 98 %. The water used was distilled. The amine solution was made up to be (3.0 or 6.0) kmol·m^{-3} at laboratory conditions. Prior to the introduction of the fluids, the cell was evacuated. About 120 cm^3 of the solution was drawn into the cell. The ethane was added to the cell by the cylinder pressure or by means of a spindle press. The circulation pump was started and the vapor bubbled through the solvent for at least 4 h to ensure that equilibrium was reached. At high pressures, a sample of the liquid phase, (2 to 20) g, depending on the solubility, was withdrawn from the cell into a 50 cm^3 sample bomb that had previously been evacuated and weighed. The bomb contained a magnetic stirring bar to help in degassing the sample. The sample bomb was reweighed to determine the mass of the sample and then attached to a vacuum rack. The rack consisted of 6.35 mm outer diameter stainless steel tubing connected to a calibrated Digigauge (range 0 to 1.0 MPa) and a 50 cm^3 buret. The rack was evacuated, and the gas was allowed to evolve from the sample bomb into the buret, which was maintained at the local atmospheric pressure and room temperature. The moles collected were calculated from the $P-V-T$ data, assuming ideal gas behavior. A correction was made for the residual ethane left in the sample at atmospheric pressure by injection of an aliquot into a gas chromatograph. At low pressures a 2 μL sample of liquid was taken from the liquid sample outlet and injected directly into the gas chromatograph. The uncertainty in the liquid phase analyses is estimated to be ± 3 %.

Table 1. Solubility of Ethane (2) in a 3.0 kmol·m^{-3} Aqueous Solution of 2-(2-Aminoethoxy)ethanol

298.15 K		323.15 K		348.15 K		373.15 K		398.15 K	
P/MPa	$x_2 \cdot 10^3$	P/MPa	$x_2 \cdot 10^3$	P/MPa	$x_2 \cdot 10^3$	P/MPa	$x_2 \cdot 10^3$	P/MPa	$x_2 \cdot 10^3$
4.225	1.33	12.04	1.69	13.12	1.87	12.06	2.25	12.64	2.53
2.99	1.04	10.07	1.69	9.76	1.83	9.72	2.04	9.90	2.29
1.73	0.713	6.05	1.46	6.89	1.62	5.93	1.57	6.42	1.79
0.643	0.300	3.55	1.02	3.02	0.986	3.03	0.941	2.91	1.03
0.263	0.129	0.951	0.376	0.894	0.351	0.989	0.365	1.06	0.445
0.093	0.0489	0.265	0.111	0.387	0.155	0.262	0.0951	0.294	0.107

Results and Discussion

The solubility of ethane in two aqueous solutions of DGA was measured at the temperatures of (298.15, 323.15, 348.15, 373.15, and 398.15) K at pressures up to 13.38 MPa. The experimental data are presented in Tables 1 and 2. The data were correlated with the model of Carroll and Mather.[4] It uses Henry's law for the aqueous solution and the Peng−Robinson[6] equation of state for the vapor phase. The salting-in ratio is defined as the mole fraction solubility in the amine solution divided by the mole fraction solubility in pure water. Although data for the solubility of ethane in water are available,[7] they are not at the exact conditions of the data presented here. Therefore, the model of Carroll and Mather[4] was used to calculate the values of the solubility of ethane in pure water. The salting-in ratios are presented in Table 3. They were

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Table 2. Solubility of Ethane (2) in a 6.0 kmol·m^{-3} Aqueous Solution of 2-(2-Aminoethoxy)ethanol

298.15 K		323.15 K		348.15 K		373.15 K		398.15 K	
P/MPa	$x_2 \cdot 10^3$	P/MPa	$x_2 \cdot 10^3$	P/MPa	$x_2 \cdot 10^3$	P/MPa	$x_2 \cdot 10^3$	P/MPa	$x_2 \cdot 10^3$
4.200	2.77	13.32	4.75	13.38	5.09	13.26	6.72	12.54	7.98
2.65	2.20	10.57	4.63	10.85	4.92	9.55	5.89	9.11	6.74
0.898	0.866	6.99	3.87	5.93	3.88	6.08	4.52	5.94	5.01
0.277	0.284	4.34	3.02	2.78	2.22	3.10	2.68	3.08	2.86
		3.01	2.37	0.873	0.81	0.848	0.87	0.938	1.01
		0.92	0.829	0.258	0.265	0.251	0.256	0.315	0.343
		0.263	0.258						

Table 3. Salting-in and Setchenow Coefficients for Ethane in Aqueous DGA Solutions

	amine concentration			
T/K	mass %	molarity	salting-in ratio	Setchenow coefficient
298.15	30.5	3.0	1.62 ± 0.08	0.161 ± 0.016
298.15	59.5	6.0	3.49 ± 0.16	0.208 ± 0.008
323.15	30.5	3.0	2.46 ± 0.24	0.300 ± 0.021
323.15	59.5	6.0	6.11 ± 0.90	0.302 ± 0.025
348.15	30.5	3.0	2.97 ± 0.08	0.363 ± 0.009
348.15	59.5	6.0	7.62 ± 0.63	0.338 ± 0.014
373.15	30.5	3.0	3.27 ± 0.51	0.395 ± 0.053
373.15	59.5	6.0	8.79 ± 0.63	0.362 ± 0.012
398.15	30.5	3.0	3.20 ± 0.37	0.388 ± 0.038
398.15	59.5	6.0	9.19 ± 0.78	0.370 ± 0.014

calculated point by point, and the values given in the table are the mean and standard deviation.

To correlate the effect of concentration of the amine solution, the Setchenow equation was used:

$$\ln S = kC_a \qquad (1)$$

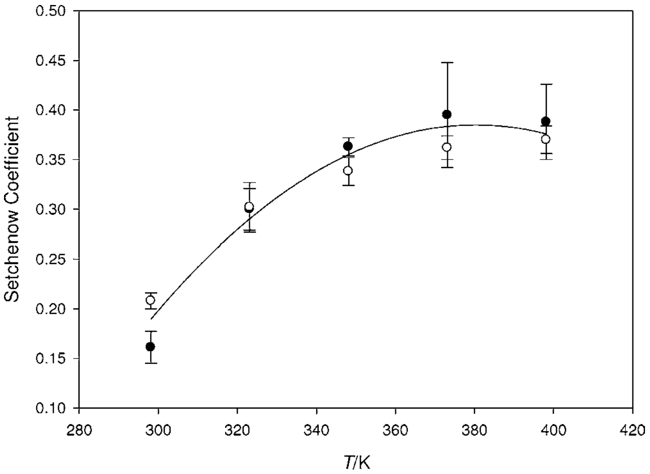

Figure 1. Temperature dependence of the Setchenow coefficients of ethane in DGA solutions: ●, 3.0 kmol·m^{-3}; ○, 6.0 kmol·m^{-3}.

where S is the salting-in ratio, k is the Setchenow coefficient, and C_a is the amine concentration, expressed as molarity, kmol·m^{-3}. The Setchenow coefficients given in Table 3 are the mean and standard deviation. They are plotted in Figure 1 as a function of temperature and have been correlated with the following quadratic equation:

$$k_{\mathrm{C2-DGA}} = -3.806 + 0.0220T - 2.897 \cdot 10^{-5}T^2 \qquad (2)$$

This correlation reproduces the experimental solubility data with an average absolute error of 4 %, about the same as the experimental uncertainty. The solubility of ethane in DGA is about twice that of methane in DGA, but only about 10 % less than that of propane in DGA.[8] The solubility of ethane in DGA is similar to that in MDEA.[2] It is greater than the solubility in MEA and DEA[9] and less than the solubility in TEA.[10]

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