Solubility of 1-(2-Dimethylaminoethyl)-5-mercapto-1*H*-tetrazole in Water, DMF, Methanol, Ethanol, 1-Propanol, 2-Propanol, 1-Butanol, and 2-Butanol between (293 and 343) K

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The solubility of 1-(2-dimethylaminoethyl)-5-mercapto-1*H*-tetrazole (DMMT) in water, *N*,*N*-dimethylformamide (DMF), methanol, ethanol, 1-propanol, 2-propanol, 1-butanol, and 2-butanol between (293 and 343) K was measured using a laser monitoring observation techinque. The results were correlated with a semiempirical equation, the calculated results of which are proved to show fine representation of experimental data.

Introduction

DMMT ($C_5H_{11}N_5S$, CAS Registry No. 61607-68-9) is a white crystalline powder and a useful chemical for an intermidiate for the synthesis of cefotiam. To determine the proper solvent and design, an optimized crystallization process is necessary to know its solubility in different solvents. In this paper, the solubilities of DMMT in water, DMF, methanol, ethanol, 1-propanol, 2-propanol, 1-butanol, and 2-butanol between (293 and 343) K were measured using a laser monitoring observation techninque at atmospheric pressure. The method employed in this work was classed as a synthetic method, which was much faster and more reliable than the analytical method.[1]

Experimental Section

Materials. A white crystalline powder of DMMT, purchased from Baiqi Chemical Technology Co., was prepared by recrystallizing from the solution of water two times. Its mass fraction purity determined by HPLC was higher than 99.4 %. Other reagents are analytical research grade reagents from Beijing Chemical Reagent Co.

Apparatus and Procedures. The solubility of DMMT was measured using an apparatus similar to that described in the literature[2] and described briefly here. A 500 mL jacketed vessel was used to determined the solubility, and the temperature was controlled to be constant (fluctuates with 0.05 K) through a thermostat water bath. The dissolution of the solute was examined by the laser beam penetrating the vessel. To prevent the evaporation of the solvent, a condenser vessel was introduced. The masses of the samples and solvents were weighted using an analytical balance (Sartorius CP224S, Germany) with an uncertainty of $\pm$ 0.0001 g. During experiments, the fluid in the glass vessel was monitored by a laser beam.[3–6] Predetermined excess amounts of solvent and DMMT of known mass were placed in the inner chamber of the vessel. The contents of the vessel were stirred continuously at a required temperature. In the early stage of the experiment, the laser beam was blocked by the undissolved particles of DMMT in the solution, so the intensity of the laser beam penetrating the vessel was lower. Along with the dissolution of the particles of the solute, the intensity of the laser beam increased gradually. When the solute dissolved completely, the solution was clear, and the laser intensity reached maximum. Then additional solute of known mass {about (1 to 5) mg} was introduced into the vessel. This procedure was repeated until the penetrated laser intensity could not return to maximum or, in other words, the last addition of solute could not dissolve completely. The interval of addition was 120 min. The total amount of the solute consumed was recorded. The same solubility experiment was conducted three times, and the mean values were used to calculate the mole fraction solubility (x_1) based on eq 1

$$x_1 = \frac{m_1/M_1}{m_1/M_1 + m_2/M_2} \tag{1}$$

where m_1 and m_2 represent the mass of the solute and solvent, respectively, and M_1 and M_2 are the molecular weight of the solute and solvent, respectively. The uncertainty of the experimental solubility values is about 0.5 %. The uncertainty in the solubility values can be due to uncertainties in the temperature measurements, weighing procedure, and instabilities of the water bath.

Results and Discussion

The solubilities of DMMT in water, DMF, methanol, ethanol, 1-propanol, 2-propanol, 1-butanol, and 2-butanol between (293 and 343) K are shown in Table 1. The relationship between temperature and solubility of DMMT is correlated with a semiempirical equation[7]

$$\ln x_1 = a + \frac{b}{T} + c \ln T \tag{2}$$

where T is the absolute temperature and a, b, and c are empirical constants. The difference between experimental and calculated results is also presented in Table 1. The values of the three parameters a, b, and c together with the root-mean-square deviations (rmsd) are listed in Table 2. The rmsd is defined as follows

$$\text{rmsd} = \left[\frac{\sum_{j=1}^{N}\left(x_{1,j} - x_{1,j}^{\text{calcd}}\right)^2}{N-1}\right]^{1/2} \tag{3}$$

where N is the number of experimental points; $x_{1,j}^{\text{calc}}$ is the solubility calculated from eq 2; and $x_{1,j}$ is the experimental value of solubility.

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Table 1. Mole Fraction Solubility of DMMT x_1 in Different Solvents between (293 and 343) K

T/K	10^4x_1	$10^4(x_1 - x_1^{calcd})$	T/K	10^4x_1	$10^4(x_1 - x_1^{calcd})$
		Water			
293.15	42.12	0.83	323.35	161.2	3.2
298.12	51.57	−0.04	328.24	198.8	3.0
303.15	63.65	−0.98	333.35	246.4	1.8
308.22	80.05	−0.96	338.21	302.6	0.7
313.35	100.9	−0.8	343.30	370.8	−5.1
318.28	126.8	0.3			
		DMF			
293.45	8.025	0.451	323.20	21.21	0.42
298.34	8.750	−0.258	328.12	25.28	0.95
303.35	10.46	−0.26	333.30	29.72	1.09
308.38	12.21	−0.53	338.22	33.54	0.20
313.25	14.62	−0.38	345.15	39.32	−1.82
318.22	17.94	0.26			
		Methanol			
293.05	1.564	−0.007	318.24	3.479	−0.008
298.17	1.856	0.015	323.25	4.138	0.034
303.15	2.195	0.043	328.23	4.855	0.024
308.20	2.536	0.011	333.15	5.712	0.030
313.05	2.914	−0.035			
		Ethanol			
293.25	0.5338	0.0072	322.55	1.326	−0.007
298.15	0.6156	−0.0063	327.45	1.555	0.019
302.95	0.7308	0.0022	332.55	1.813	0.040
308.10	0.8478	−0.0117	338.05	2.058	−0.003
312.94	0.9910	−0.0085	342.20	2.265	−0.037
318.15	1.177	0.006			
		1-Propanol			
293.17	0.5795	−0.0088	323.20	1.610	0.008
298.14	0.7343	0.0098	328.34	1.762	−0.039
303.25	0.8518	−0.0289	332.95	1.887	−0.088
308.12	1.066	0.023	338.18	2.160	−0.008
313.15	1.265	0.043	343.16	2.406	0.066
318.23	1.399	−0.012			
		2-Propanol			
293.15	0.3471	−0.0104	323.25	0.7958	−0.0107
298.28	0.4153	0.0058	328.16	0.9088	−0.0151
303.35	0.4795	0.0107	333.35	1.055	−0.012
308.14	0.5427	0.0092	338.32	1.229	0.003
313.25	0.6149	0.0020	343.45	1.441	0.026
318.20	0.6959	−0.0059			
		1-Butanol			
293.15	0.6108	−0.0079	323.00	1.119	−0.020
298.21	0.6925	0.0088	328.14	1.261	−0.009
303.35	0.7655	0.0075	333.05	1.411	0.000
308.14	0.8492	0.0136	338.12	1.582	0.008
313.05	0.9473	0.0227	343.10	1.786	0.032
318.28	1.029	−0.002			
		2-Butanol			
293.35	0.3159	0.0047	323.00	0.7523	0.0226
298.37	0.3493	0.0096	327.33	0.9183	0.0414
303.25	0.4116	0.0327	330.85	1.095	0.067
308.24	0.4365	0.0029	335.57	1.329	0.041
313.15	0.4842	−0.0215	340.50	1.647	−0.006
318.12	0.6194	0.0165			

Table 2. Parameters of Equation 2 for DMMT in Different Solvents

solvent	a	b	c	10^5rmsd
water	−152.55	3168.7	23.985	22.90
DMF	−60.612	−273.74	9.5674	8.03
methanol	−171.59	4902.0	25.721	0.28
ethanol	−18.234	−2148.9	2.7654	0.02
1-propanol	281.87	−16000	−41.726	0.42
2-propanol	−141.77	3852.0	20.841	0.12
1-butanol	−122.00	3499.5	17.669	0.16
2-butanol	−681.19	28370	101.05	0.32

From Table 1 and Table 2, we could elicit the conclusions: (1) The solubilities of DMMT in alcohols increase with increase of temperature, but the increment with temperature varies according to different solvents. (2) From Table 2, we could find parameter c in all solvents is relatively small, which is true for many compounds under most conditions, so the last term of eq 2 is neglected in many cases. (3) It can be seen that DMMT dissolved much more in water than in the other seven solvents, and the solubility in 2-butanol is the lowest. (4) All the experimental data can be regressed by eq 2 for solvents. The experimental solubility and correlation equation in this work can be used as essential models in the manufacturing and purifying processes of DMMT in industry.

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