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Solubility of N-chloro succinimide in different pure solvents in the temperature range from 278.15 K to 333.15 K

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Abstract−Solubility data were measured for N-chloro succinimide in pure n-butanol, ethyl acetate, acetone, isopropanol, tetrahydrofuran, acetonitrile and acetic anhydride at the temperature range between 278.15 K and 333.15 K under atmospheric pressure by gravimetric method. The solubility of N-chloro succinimide in those selected solvents increased with increasing temperature. The solubility data were correlated with the modified Apelblat equation and the van't Hoff equation to obtain the model parameters. The experimental results could be useful for optimizing the process of purification of N-chloro succinimide in industry. Isopropanol could be the excellent solvent in the crystallization of N-chloro succinimide.

Key words: N-chloro Succinimide, Solubility, Measure, Correlation

INTRODUCTION

N-chloro succinimide (NCS) with the IUPAC name 1-chloro-2,5-Pyrrolidinedione ($C_4H_4NO_2Cl$; CASRN: 128-09-6; molecular mass 133.54) is a white crystalline powder. Its chemical structural is given in Fig. 1. N-chloro succinimide is a multifunctional organic regent, as well as a chemical intermediate with wide use and optimum application prospect in the chemistry industry. It is an important halogenation reagent widely used in organic synthesis [1-4]. For the production of N-chloro succinimide in industrial processes, it is commonly synthesized by the reaction of succinic acid [5]. The crude product contains a series of impurities and must be purified by crystallization [6].

The crystallization separation operation is widely used in chemical engineering as a result of low energy consumption and high purity. More particularly, knowledge of an accurate solubility is needed for the design of separation processes such as extractive crystallization or for the safe operation of different processing units such as distillation columns, absorption units, and extraction plants. They can also supply basic and theoretical data for industrial production [7,8].

In the purification process of N-chloro succinimide, to determine proper solvents and design an optimized production, it is very important to know the solubility of N-chloro succinimide in different solvents. Unfortunately, no experimental solubility data of N-chloro succinimide in different solvents are currently available in the literature. In this study, the solubility of N-chloro succinimide in pure n-butanol, ethyl acetate, acetone, isopropanol, tetrahydrofuran, acetonitrile and acetic anhydride was measured in the temperature ranging from 278.15 K to 333.15 K under atmospheric pressure by gravimetric method so as to provide essential data for the development of crystallization processes. The solubility data were fitted to the modified Apelblat equation and the van't Hoff equation to obtain the empirical parameters.

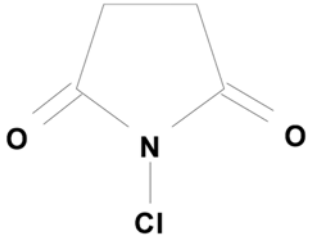

Fig. 1. The molecular structure of N-chloro succinimide.

EXPERIMENTAL SECTIONS

1. Materials

N-chloro succinimide used during the solubility measurements was purchased from Sinopharm Chemical Regent Co., Ltd. Its purity was greater than 99.5% in mass fraction, measured by high performance liquid chromatography (HPLC type DIONEX P680 DIONEX Technologies). The n-butanol, ethyl acetate, acetone, isopropanol, tetrahydrofuran, acetonitrile and acetic anhydride for dissolving were analytical purity grade with mass fraction purity higher than 99.5%, which are supplied by Shanghai Shenbo Chemical Co., Ltd. All chemicals were used as received without further purification.

2. Apparatus and Procedures

Methods of measuring the solubility of a solid in a solvent can be classified as analytical and synthetic [9,10]. We adopted the simple analytical method to determine the solubility of N-chloro succinimide in the seven solvents with their temperatures ranging from 278.15 K to 333.15 K. The advantages of the analytical method are simple and reliable due to the possibility of measuring a large number of samples simultaneously. However, it also has disadvantages, such as being tedious and time-consuming.

The apparatus for solubility measurement was similar to that de-

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scribed in the literature [11,12]. In the experiments, 10 ml glass test tubes with stoppers were used to prepare saturated solution (about 8 ml) of N-chloro succinimide with excess solid solute in the different solvents. Then the tubes were directly placed in a jacketed vessel (1,000 ml) with water circulated through the outer jacket from a smart thermostatic bath (model: DC-2006, provided by Ningbo Scientz Biotechnology Co., Ltd.) at the required temperature, with a temperature stability of ±0.1 °C. A mercury-in-glass thermometer with an uncertainty of ±0.1 °C was inserted into the inner chamber of the vessel to measure the temperature. The contents of the tubes were stirred continuously at certain temperature by a magnetic stirrer. To ensure the solid-liquid equilibrium, the solution was constantly stirred for at least 12 h at the specified temperature, and then the stirring was stopped to let the solution settle for at least 3 h. A volume of 1 ml of the clear upper saturated solution was taken from the test tube and transferred into a 5 ml beaker, and the total weight was measured immediately by an analytical balance (model: BSA224S, Sartorius Scientific Instruments (Beijing) Co., Ltd.) with an uncertainty ±0.0001 g. The empty breaker should be weighed before containing the saturated solution. Before the weight of the beaker containing no solvent is measured, it must be put into a dryer oven at 308 K for more than seven days. Each experiment was repeated three times to obtain a fine average result. The saturated mole fraction solubility of N-chloro succinimide (x) in solvents can be calculated from the following equation:

$$x = \frac{m_1/M_1}{m_1/M_1 + m_2/M_2} \quad (1)$$

Where m_1 and m_2 represent the mass of the solute and the solvent, and M_1 and M_2 are the molecular weight of the solute and the solvent, respectively.

RESULTS AND DISCUSSION

The solubility data of N-chloro succinimide in ethyl acetate, acetonitrile, acetone, tetrahydrofuran, isopropanol, n-butanol and acetic anhydride in the temperature ranging between 278.15 K and 335.15 K are listed in Table 1, where T represents the absolute temperature and x and x_c are the mole fraction solubility of the experimental and the calculated values, respectively. The relative deviations (RDs) between the experimental values and the calculated values are also presented in Table 1. The RDs are calculated according to the following equation:

$$RD = \frac{x - x_c}{x} \quad (2)$$

Table 1. Mole fraction solubility (x) of succinimide in selected organic solvents with the temperature range between (278.15 and 335.15) K

T/K	103x	103xc	100RD	T/K	103x	103xc	100RD
			n-Butanol				
278.15	4.5427±0.0005	4.4741	1.51	308.15	19.2193±0.0006	19.0577	0.84
283.15	5.9392±0.0003	6.0842	−2.44	313.15	22.1693±0.0004	22.3649	−0.88
288.15	8.0257±0.0002	8.0407	−0.19	318.15	25.3706±0.0003	25.7343	−1.43
293.15	10.2547±0.0004	10.3451	−0.88	323.15	29.5265±0.0005	29.0669	1.56
298.15	13.0653±0.0006	12.9791	0.66	328.15	32.0445±0.0002	32.2618	−0.68
303.15	16.0777±0.0009	15.9033	1.08	333.15	35.2801±0.0008	35.2221	0.16
			Ethyl acetate				
278.15	24.8230±0.0006	24.6066	0.87	308.15	44.7534±0.0005	44.8337	−0.18
283.15	26.5771±0.0005	26.7362	−0.60	313.15	50.4359±0.0003	50.5705	−0.27
288.15	29.2866±0.0007	29.2689	0.06	318.15	57.0976±0.0009	57.3109	−0.37
293.15	32.2735±0.0011	32.2646	0.03	323.15	65.0270±0.0008	65.2339	−0.32
298.15	35.7883±0.0009	35.7961	−0.02	328.15	75.8404±0.0005	74.5529	1.70
303.15	39.9178±0.0004	39.9508	−0.08	333.15	84.8193±0.0003	85.5224	−0.83
			Acetone				
278.15	67.5096±0.0002	67.4317	0.12	308.15	82.7341±0.0004	83.1167	−0.46
283.15	66.5827±0.0005	66.7129	−0.20	313.15	90.6118±0.0008	90.9896	−0.42
288.15	67.2996±0.0003	67.3308	−0.05	318.15	100.8905±0.0006	100.9293	−0.04
293.15	69.2257±0.0004	69.2289	−0.01	323.15	114.3694±0.0004	113.3422	0.90
298.15	72.8510±0.0007	72.4248	0.59	328.15	128.2313±0.0007	128.7562	−0.41
303.15	76.9533±0.0009	77.0033	−0.06				
			Isopropanol				
278.15	4.4010±0.0004	4.3165	2.03	308.15	39.6238±0.0006	39.4747	0.38
283.15	6.6198±0.0006	6.5194	1.52	313.15	51.2732±0.0002	51.8963	−1.22
288.15	10.1582±0.0008	9.9618	1.93	318.15	65.6681±0.0004	66.5392	−1.33
293.15	14.6815±0.0005	14.7151	−0.23	323.15	84.9055±0.0008	83.3217	1.87
298.15	21.2056±0.0012	21.0556	0.71	328.15	101.7331±0.0013	102.0356	−0.30
303.15	29.2070±0.0009	29.2392	−0.11	333.15	122.1726±0.0009	122.3477	−0.14

Table 1. Continued

T/K	103x	103xc	100RD	T/K	103x	103xc	100RD
			THF				
278.15	75.0229±0.0005	76.8899	−2.49	308.15	127.4057±0.0007	127.9778	−0.45
283.15	81.3856±0.0003	80.3243	1.30	313.15	142.8947±0.0008	145.9838	−2.16
288.15	87.0391±0.0007	85.6593	1.59	318.15	169.5606±0.0017	168.3366	0.72
293.15	94.2152±0.0009	92.7718	1.53	323.15	193.9414±0.0005	196.0815	−1.10
298.15	101.6645±0.0004	101.9308	−0.26	328.15	236.1288±0.0008	230.5596	2.36
303.15	113.3196±0.0006	113.5041	−0.16	333.15	270.9602±0.0003	273.4904	−0.93
			Acetonitrile				
278.15	54.2426±0.0004	54.6236	−0.70	308.15	112.1052±0.0003	111.8663	0.21
283.15	59.7058±0.0007	59.2224	0.81	313.15	131.3805±0.0004	132.1083	−0.55
288.15	65.3944±0.0009	65.3076	0.13	318.15	157.4301±0.0008	157.7341	−0.19
293.15	73.3784±0.0003	73.1627	0.29	323.15	191.7680±0.0007	190.2634	0.78
298.15	82.7455±0.0014	83.1726	−0.52	328.15	230.7827±0.0016	231.6931	−0.39
303.15	95.9315±0.0002	95.8491	0.09	333.15	284.7933±0.0006	284.6514	0.05
			Acetic anhydride				
278.15	43.6071±0.0006	43.9166	−0.71	308.15	79.0873±0.0004	78.5106	0.73
283.15	46.5893±0.0007	46.6481	−0.13	313.15	89.1384±0.0003	90.4094	−1.43
288.15	50.3660±0.0003	50.3494	0.03	318.15	103.0114±0.0007	105.1994	−2.12
293.15	56.4095±0.0008	55.1595	2.22	323.15	125.6748±0.0005	123.5998	1.65
298.15	59.7084±0.0002	61.2715	−2.62	328.15	146.9161±0.0009	146.5347	0.26
303.15	70.4975±0.0005	68.9429	2.21	333.15	174.7498±0.0015	175.1916	−0.25

The relationship between temperature and mole fraction solubility in different solvents is described by the modified Apelblat equation as follows [13,14]:

$$\ln(x_c)=A+B/(T/K)+C\ln(T/K) \quad (3)$$

Where A, B and C are model parameters. The constants A and B represent the variation in the solution activity coefficient and provide an indication of the effect of non-ideal solution on the solute solubility, while the constant C reflects the temperature influence on the fusion enthalpy [15].

The van't Hoff model is an alternate way to describe solid-liquid equilibrium, as first proposed by Grant et al. [16]. In this study, the solubility data were also correlated with the van't Hoff equation which is shown as follows:

$$\ln(x_c)=a+b/(T/K) \quad (4)$$

Table 2. Parameters of the modified Apelblat equation for succinimide in different organic solvents

Solvents	A	B	C	10^3 rmsd	100RAD	R^2
n-Butanol	399.9	−21243.6	−58.4	0.2103	1.03	0.9996
Ethyl acetate	−223.836	8199.047	33.875	0.4414	0.44	0.9995
Acetone	−427.03	18085.26	63.84	0.3904	0.27	0.9996
Isopropanol	452.2	−25481.6	−65.0	0.5687	0.98	0.9998
THF	−396.94	16043.99	59.82	2.2743	1.26	0.9986
Acetonitrile	−426.75	16841.48	64.55	0.6065	0.39	0.9999
Acetic anhydride	−391.94	15634.15	59.10	1.2214	1.20	0.9991

Table 3. Parameters of van't Hoff equation for succinimide in different organic solvents

Solvents	A	B	10^3 rmsd	100RAD	R^2
n-Butanol	5.69	−2993.09	1.2247	10.02	0.9852
Ethyl acetate	4.41	−2300.40	2.1002	4.73	0.9877
Acetone	2.03	−1365.71	6.4721	6.91	0.8962
Isopropanol	12.50	−4854.49	2.5609	14.91	0.9955
THF	6.21	−2523.95	11.0696	8.56	0.9674
Acetonitrile	8.67	−3325.40	9.8000	9.1142	0.9809
Acetic anhydride	6.43	−2741.37	6.5718	8.2651	0.9740

Where T is the temperature in K, and a and b are the parameters of the equation.

Using the values in Table 1, the parameters of A, B and C were estimated and presented in Table 2, and the parameters of a and b were listed in Table 3, together with the root-mean-square deviations (RMSDS) and the relative average deviation (RAD). The RMSD is defined as follows:

$$\mathrm{RMSD}=\sqrt{\frac{\sum_{i=1}^{N}(x_{ci}-x_i)^2}{N}} \tag{5}$$

The relative average deviation (RAD) is obtained according to the following equation:

$$\mathrm{RAD}=\frac{1}{N}\sum_{i=1}^{N}\left|\frac{x_i-x_{ci}}{x_i}\right| \tag{6}$$

Where N is the number of experimental points obtained in each set to match the number of temperatures used.

As we can see from Table 1 and Table 2, the calculated solubilities of N-chloro succinimide in a total of seven pure solvents show good agreement with the experimental data from the small RMSDS. The relative average deviations are 1.03%, 0.44%, 0.27%, 0.98%, 1.26%, 0.39% and 1.20%, respectively; the absolute value of relative deviations among all of the values does not exceed 2.62%, which indicates that the modified Apelblat equation can be used to correlate the solubility data of N-chloro succinimide in the selected pure solvents. The average value of the uncertainty for each solvent is 0.0005, 0.0006, 0.0005, 0.0007, 0.0007, 0.0007, 0.0006, respectively. In this work, both the modified Apelblat equation and the van't Hoff equation can be used to correlate the solubility data with the average RMSD of 0.8161 and 5.6856, respectively. Thus, the Apelblat equation is more accurate than the van't Hoff equation for this system. The results mentioned above suggest that the solubility data and the correlation equations in this work can be used as essential data and models in the purification process of N-chloro succinimide.

The x/T-curves of N-chloro succinimide in all selected pure solvents are shown in Fig. 2. From Fig. 2, it can be seen that the solubility of N-chloro succinimide in each of the seven solvents is a function of temperature and increases with the increase of the temperature, but the increment of solubility with temperature is different in different solvents. Also, the solubility of N-chloro succinimide is especially high in acetonitrile and tetrahydrofuran but very low in n-butanol and ethyl acetate. As for the rest of the solvents, the solubility in isopropanol varies much more obviously with temperature than in the other three solvents. The solubility in isopropanol is lower than the one in acetone and acetic anhydride when the temperature is low, but contrary to them at higher temperature, which presents a potential advantage in the crystallization of N-chloro succinimide.

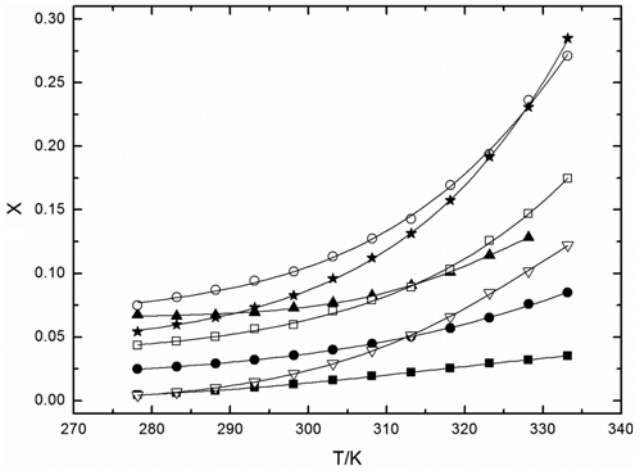

Fig. 2. Mole fraction solubilities of N-chloro succinimide in selected pure solvents: ■, n-butanol; ●, ethyl acetate; ▲, acetone; ▽, isopropanol; ○, tetrahydrofuran; ★, acetonitrile; □, acetic anhydride. Solid lines, calculated from Eq. (3).

As we all know, a popular rule called "like dissolves like" is usually used for predicting solubility and identifying a suitable solvent for extraction of some compounds. This statement means that a solute will dissolve best in a solvent that has a similar chemical structure or polarity to itself. This is simplistic since many solvent-solute interactions are neglected, but it is a useful rule of thumb in some cases. It's obvious that the polarity of the solvents is not the only factor to determine the solubility of N-chloro succimide in the solvents investigated as there is no solubility sequence available from Fig. 2. In addition, from Fig. 1, we can see a cyclic structure with two carbonyl groups in the molecule of N-chloro succinimide, which may suggest that solvents containing one or two carbonyl groups such as acetone should have given relatively high solubility for N-chloro succinimide, but the fact is not such. The solubility of N-chloro succinimide in acetone is not the highest; the solubility is especially high in acetonitrile and tetrahydrofuran. So it's inferred that the solubility of N-chloro succinimide in some solvents is affected by other factors such as solvent-solute interactions.

CONCLUSION

The solubility of N-chloro succinimide in n-butanol, ethyl acetate, acetone, isopropanol, tetrahydrofuran, acetonitrile and acetic anhydride was measured at atmospheric pressure in the temperature range from 278.15 K to 333.15 K by an analysis method. We can draw the following conclusions: (1) The solubility of N-chloro succinimide in the selected solvents increases with increasing temperature, but the increments with temperature vary for different solvents; (2) The experimental data can be correlated using the modified Apelblat equation, and the solubility calculated by the Apelblat equation shows good agreement with experimental values; (3) The experimental solubility and correlation in this work can be used as essential data and models in the purification process of N-chloro succinimide.

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REFERENCES

1. Y. Mei, P. A. Bentley and J. Du, *Tetrahedron Lett.*, **50**, 4199 (2009).

2. X. Y. Wang, L. Q. Chang, H. Zhou and K. D. Zhang, *Chinese J. Chem.*, **24**, 1214 (2006).
3. P. Virgil and G. Cristian, *J. Polymer Sci., Part A: Polymer Chem.*, **43**, 5283 (2005).
4. T. Toshiki, H. Yuta, M. Naoya and O. Teruhisa, *Diamond and Related Materials*, **18**, 1174 (2009).
5. B. G. Xu and Y. J. Zhang, *Tianjin Huagong*, **20**, 49 (2006).
6. A. I. Vogel, Vogel's Practical Organic Chemistry, Third Ed., London (1956).
7. PJ . Gandhi and Z. V. P. Murthy, *J. Chem. Eng. Data*, **55**, 5091 (2010).
8. S. Wang, Q. S. Li. and Z. Li, *Korean J. Chem. Eng.*, **25**, 558 (2008).
9. S. Brandani, V. Brandani and D. Flammi, *J. Chem. Eng. Data*, **39**, 201 (1994).
10. H. X. Hao, J. K. Wang and Y. L. Wang, *J. Chem. Eng. Data*, **49**, 1697 (2004).
11. H. Y. Yang and C. Rasmuson, *J. Chem. Eng. Data*, **55**, 5091 (2010).
12. Y. L. Zheng, X. S. Liu, L. J. Luan and L. H. Wang, *J. Chem. Eng. Data*, **55**, 3690 (2010).
13. M. Emanuel and A. Alexander, *J. Chem. Thermodyn*, **34**, 1127 (2002).
14. A. Alexander and M. Emanuel, *J. Chem. Thermodyn*, **31**, 85 (1999).
15. A. Alexander and M. Emanuel, *J. Chem. Thermodyn*, **29**, 1527 (1997).
16. D. J. W. Grant, M. Mehdizadeh, A. H. L. Chow and J. E. Fairbrother, *Int. J. Pharm.*, **18**, 25 (1984).