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Short Communication

Measurement and correlation of solubility of β-cyclodextrin in sucrose solution

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ABSTRACT

The solubility of β-cyclodextrin in 5% sucrose solution has been measured by a laser monitoring technique from 293.45 to 357.45 K at atmospheric pressure. The experimental data were correlated with the modified Apelblat equation, and the model estimations showed good agreement with the experimental data.

Keywords: Solubility, β-cyclodextrin, sucrose, solubility model.

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INTRODUCTION

Cyclodextrin is a cyclic oligosaccharide that is obtained from D-glucopyranose by α-1,4 glycosidic bond polymerization. β-cyclodextrin is the common one which contains seven D-glucopyranose units (Saenger, 1980). β-cyclodextrin with the special structure and properties of annular hollow cylinder, internal hydrophobic and outer ring hydrophilic (Liu et al., 2001), it is widely used in food, pharmaceutical and cosmetic industries. But the solubility of β-cyclodextrin in water is lower compared with other oligomers, which restrict its applications. In order to improve its solubility, sucrose was added incyclodextrin solution.

In this view, the studies on the intersolubility of β-cyclodextrin and sucrose are important although there is little reports on the solubility of β-cyclodextrin in sucrose solution. In this paper, the solubility of β-cyclodextrin in sucrose solution was studied, and the experimental data were correlated with the modified Apelblat equation, which provide reference for its application.

EXPERIMENTAL

Materials

β-Cyclodextrin was of AR grade, it was obtained from Shanghai Chemical Reagent Co. Sucrose was of AR grade, which was obtained from Sinopharm Chemical Reagent Co. Deionized water was used.

Solubility measurement

Commonly used methods for solubility determination were the equilibrium method (Jia et al., 2014) and the dynamic method (Wang et al., 2014). The solubility of β-cyclodextrin in sucrose solution was measured by a dynamic method at atmospheric pressure. The experiments were carried out in a 50 ml jacketed glass vessel with a magnetic stirrer; a constant temperature (±0.02 K) was maintained at the required temperature by circulating water through the outer jacket from a thermoelectric controller. A glass bushing with a mercury glass thermometer was inserted into the inner chamber of the vessels for the measurement of the solution temperature and the laser monitoring observation technique was used to determine the dissolution temperature. The uncertainty of temperature was ±0.02 K (calibrated by using standard thermometer).

An excess amount of β-cyclodextrin was added to the solvent, and the solvent was weighed using an electronic balance with an uncertainty of ±0.0001 g and transferred into the vessel. In the early stage of the experiment, due to large number of solute that did not dissolve, the laser beam was blocked by the particles of β-cyclodextrin in the solution, so the intensity of the laser beam penetrating the vessel was lower. Then can rapidly increasing temperature, when most of the solute dissolved, heated the vessel at a rate of 1 $K \cdot h^{-1}$ until the system was in equilibrium, the intensity of the laser beam penetrating the vessel reached the maximum, and the temperature was recorded. The solubility expressed by mole fraction was calculated as follows (Shi et al., 2006).

$$x = \frac{m_1/M_1}{m_1/M_1+m_2/M_2+m_3/M_3} \quad (1)$$

Where m_1 represents the mass of solute, m_2 and m_3 represent the mass of solute and solvent respectively in the sucrose solution. M_1, M_2 and M_3 are the molecular mass respectively.

Test of apparatus

To prove the feasibility and the uncertainty of the measurement, the solubility of NaCl in water was measured and compared with the values reported in the literature (Li et al., 2014). The experimental measurements agreed with the reported values with a mean relative deviation of 1.24%. The measured values are listed in Table 1.

Table 1. Solubility of NaCl in water.

T/K	*x*	*x*(lit)[6]	100*RD*
293.15	0.1015	0.0999	1.58
313.15	0.1021	0.1011	0.98
333.15	0.1045	0.1033	1.15
373.15	0.1108	0.1094	1.26

RESULTS AND DISCUSSION

The measured solubilities of β-cyclodextrin in 5% sucrose solution at different temperatures were presented in Table 2. The experimental data were correlated with the modified Apelblat equation:

$$\ln x = A + \frac{B}{T} + C\ln T \quad (2)$$

Where x is the mole fraction solubility of β-cyclodextrin. T is the absolute temperature. A, B and C are the model parameters.

The solubility curve by Equation 2 was shown in Figure 1. The fitting accuracy with Apelblat equation was evaluated by Root Mean Square Deviation (RMSD), Relative Deviation (RD), Relative Average Deviation (RAD).

$$\mathrm{RMSD} = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(x_{ci} - x_i)^2} \quad (3)$$

$$\mathrm{RD} = \frac{x_i - x_{ci}}{x_i} \quad (4)$$

$$\mathrm{RAD} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{x_i - x_{ci}}{x_i}\right| \quad (5)$$

Where n is the number of experimental points, x_{ci} represents the solubilities calculated from Equation 2, and x_i represents the experimental solubility values. The calculated values were listed in Table 2 and the parameters of modified Apelblat equation and calculated values of RMSD and RAD were listed in Table 3.

From Table 2, it can be found that the solubility of β-cyclodextrin increases with the increase of temperature.

Table 2. Mole fraction solubilities of β-cyclodextrin in sucrose solution.

T/K	$x_i \times 10^4$	$x_{ci} \times 10^4$	*RD*
293.45	2.5254	2.0534	0.1869
298.55	3.1629	2.7116	0.1427
303.35	3.9798	3.5106	0.1179
308.25	4.8223	4.5541	0.0556
312.65	5.7222	5.7369	-0.0026
318.25	7.2819	7.6676	-0.0530
323.25	9.6630	9.8998	-0.0245
328.15	12.1283	12.6772	-0.0453
333.05	15.1430	16.1850	-0.0688
337.55	19.6502	20.2032	-0.0281
342.95	25.8855	26.2783	-0.0152
347.55	32.7985	32.7862	0.0004
352.65	42.4532	41.7832	0.0158
357.45	52.8033	52.3556	0.0085

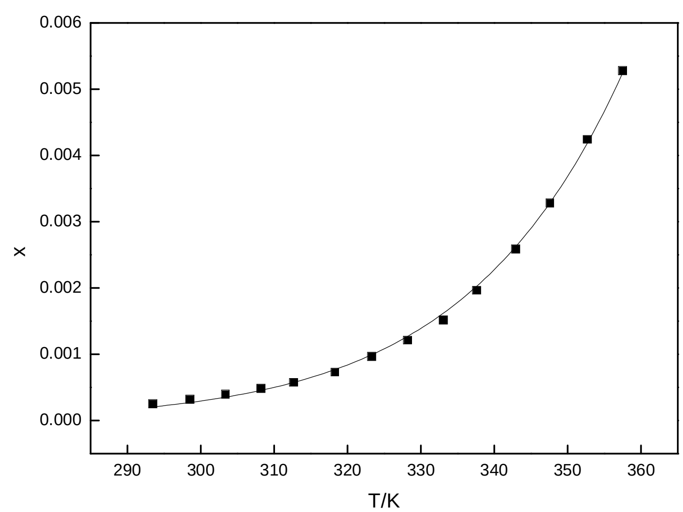

Figure 1. The solubility of β-Cyclodextrin in 5% sucrose solution at different temperature.

From Table 3, it can be found that the calculated solubilities show good agreement with the experimental data. The relative average deviation is 5.5%, which indicates that the modified Apelblat equation is suitable to correlate the solubility data of β-cyclodextrin in sucrose solution.

Table 3. Parameters of β-cyclodextrin in sucrose solution.

A	*B*	*C*	R^2	RMSD × 10^5	RAD
-122.21	974.79	19.43	0.9988	1.32	0.055

CONCLUSION

The solubility of β-cyclodextrin in sucrose solution has been determined from 293.45 to 357.45 K by suitable experimental method and solubility apparatus.

The modified Apelblat equation based on solid-liquid phase equilibrium principles is used to correlate the solubility data of β-cyclodextrin in sucrose solution, and the average relative deviation is 5.5 %, the solubilities calculated by the model show good agreement with the experimental data.

The experimental solubility and correlation equation in this work can be relevant for further applications of β-cyclodextrin.

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