Journal of Thermal Analysis and Calorimetry, Vol. 74 (2003) 335–340

CALORIMETRIC STUDY AND THERMAL ANALYSIS OF BERBERINE SULPHATE

*F. Xu, L. X. Sun**, *Z. C. Tan, X. Z. Lan, P. Yu and T. Zhang*

Thermochemistry Laboratory, Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian 110623, P.R. China

(Received December 11, 2002; in revised form April 17, 2003)

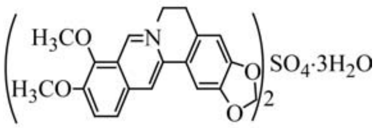
Abstract

The heat capacities of berberine sulphate [$(C_{20}H_{18}NO_4)_2SO_4 \cdot 3H_2O$] were measured from 80 to 390 K by means of an automated adiabatic calorimeter. Smoothed heat capacities, $\{H_T–H_{298.15}\}$ and $\{S_T–S_{298.15}\}$ were calculated. The loss of crystalline water started at about 339.3±0.2 K, and its peak temperature was 365.8±0.6 K. The peak temperature of decomposition for berberine sulphate was at about 391.4±0.4 K by DSC curve. TG-DTG analysis of this material was carried out in temperature range from 310 to 970 K. TG and DSC curves show that there is no melting in the whole heating process.

Keywords: berberine sulphate, DSC, molar heat capacity, TG-DTG, thermal analysis

Introduction

Berberine sulphate is a kind of benzyl isoquinoline alkaloid. Its structure is as follows:



It exists in many plants and can be extracted from these plants [1]. Its molecular formula is $(C_{20}H_{18}NO_4)_2SO_4 \cdot 3H_2O$. The berberine has effects of anti-bacteria, anti-inflammation and restraining the growth of tumor cells [2].

As a raw material of drug, the thermodynamic properties of the berberine are significant not only in its further theoretical studies but also in its clinical applications. Heat capacities determinations of various compounds have attracted many researchers' attention [3–12]. Giron has reviewed the applications of thermal analysis and coupled techniques in pharmaceutical industry [13]. To our best knowledge, till now there is no any report about study of thermal behavior of berberine sulphate. In

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* Author for correspondence: E-mail: lxsun@dicp.ac.cn

1388–6150/2003/ $ 20.00

Akadémiai Kiadó, Budapest
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order to provide accurate thermodynamic data, the thermal behaviors of berberine sulphate were systematically investigated by using an adiabatic calorimetry, DSC and TG-DTG in the present study.

Experimental

Adiabatic calorimetry

The heat capacity measurements were performed by means of a high-precision automatic adiabatic calorimeter over the temperature range from 78 to 400 K. The mass of berberine sulphate used for the heat capacity measurements was 1.1047 g, which was equivalent to 1.3425 mmol based on its molar mass of 822.84 g mol^{-1}. The principle and structure of the adiabatic calorimeter were described in detail in our previous publications [3, 8, 11, 14, 15]. In order to verify the accuracy of the calorimeter, the molar heat capacity measurements of the reference standard material, α-Al_2O_3, were made prior to heat capacity measurement of berberine sulphate. The deviations of our experimental results from the smoothed curve lie within ±0.1%, while the inaccuracy was within ±0.2% compared with those of the National Bureau of Standards [16] in the entirely experimental temperature range.

TG-DTG analysis

A thermogravimetric analyzer (Model TGA2950, TA Instruments, USA) was used for TG measurements of the berberine sulphate under high purity (99.999%) nitrogen atmosphere. The heating rate was 10°C min^{-1} and the flow rate of nitrogen was 30 mL min^{-1}.

DSC analysis

A differential scanning calorimeter (DSC141, Setaram Co., France) was used to perform the thermal analysis of berberine sulphate. The heating rate was 10°C min^{-1} and the flow rate of nitrogen was 50 mL min^{-1}.

Sample

The berberine sulphate sample [$(C_{20}H_{18}NO_4)_2SO_4\cdot 3H_2O$] used in the present study was purchased from Wako Pure Chemical Industries, Ltd. Its purity was proved to be more than 99.0% by iodometry. The water content ($3H_2O$) in the sample was analyzed and confirmed by Karl Fischer method.

Results and discussion

The low-temperature experimental molar heat capacities of berberine sulphate are shown in Fig. 1. The temperature increment for each experimental point was about 3 K over the whole temperature range. The molar heat capacities of the sample ob-

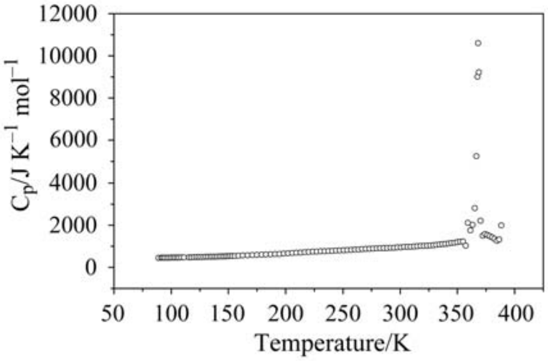

Fig. 1 $C_p \sim T$ curve of berberine sulphate obtained by adiabatic calorimetry

tained from high-precision automatic adiabatic calorimeter are fitted to the following polynomials in reduced temperature (X) by means of the least square fitting,

$$C_{p,m}(\text{J mol}^{-1}\ \text{K}^{-1})=726.79+414.92X-6.3018X^2-202.15X^3+ \\ +55.466X^4+180.21X^5+66.126X^6 \quad (1)$$

where $X=(T-221)/133$, T is the absolute temperature (K), the linear regression coefficient of the fitting, $R^2=0.9997$. This equation is valid from 88 to 354 K. The standard deviation of the experimental points from the smoothed values in this temperature region is within ±0.5%. Thermodynamic functions of $(C_{20}H_{18}NO_4)_2SO_4 \cdot 3H_2O$ at selected temperature intervals were obtained by calculation from the above polynomial (Eq. 1) for the heat capacities, where

$$H_T-H_{298.15}=\int_{298.15}^{T} C_{p,m}\,dT, \quad S_T-S_{298.15}=\int_{298.15}^{T} \frac{C_{p,m}}{T}\,dT.$$

Values for the thermodynamic function data thus obtained are presented in Table 1. The anomaly peak appears in the above $C_p \sim T$ curve at about 358 and 368 K was proved to be produced from sample decomposition by repetitive automated adiabatic calorimeter (repeated in 3 times). The following TG-DSC experiments demonstrated the decomposed process included loss of the crystalline water and releasing of CO. The results obtained from the automated adiabatic calorimeter showed that there is no thermal anomaly in the range of 80–352 K, which means that this material is stable in this temperature range.

The results obtained by TG-DTG under N_2 atmosphere are shown in Fig. 2. Figure 2 shows that there are three steps of mass loss for berberine sulphate. In the first step, it shows a mass loss of 6.5% at 319–354 K, which suggested that the residual product should be $(C_{20}H_{18}NO_4)_2SO_4$, as the theoretical mass loss (%) of 3 mol H_2O from $(C_{20}H_{18}NO_4)_2SO_4 \cdot$ $3H_2O$ is 6.6% when the final residual is $(C_{20}H_{18}NO_4)_2SO_4$. In the second step, the residual $(C_{20}H_{18}NO_4)_2SO_4$ from the first step was further decomposed at 354–425 K, with a mass loss of 7.2% corresponding to the generation of 2 mol CO from 1 mol of $(C_{20}H_{18}NO_4)_2SO_4$ (calcd., 7.3%).

Table 1 Calculated thermodynamic function data of $(C_{20}H_{18}NO_4)_2SO_4\cdot 3H_2O$

T/ K	C_p/ J mol^{-1} K^{-1}	H_T–$H_{298.15}$/ J mol^{-1}	S_T–$S_{298.15}$/ J mol^{-1} K^{-1}	T/ K	C_p/ J mol^{-1} K^{-1}	H_T–$H_{298.15}$/ J mol^{-1}	S_T–$S_{298.15}$/ J mol^{-1} K^{-1}
90	450.68	–107	–1110	230	754.78	–42.7	–228.9
95	454.9	–104.8	–1047	235	770.17	–39.98	–211.4
100	459.49	–102.6	–988.3	240	785.38	–37.21	–194.1
105	464.48	–100.4	–933.9	245	800.36	–34.38	–177
110	469.91	–98.24	–883.2	250	815.09	–31.48	–160
115	475.81	–96.09	–835.9	255	829.52	–28.52	–143.1
120	482.21	–93.95	–791.8	260	843.66	–25.49	–126.3
125	489.14	–91.8	–750.5	265	857.51	–22.4	–109.6
130	496.61	–89.65	–711.8	270	871.1	–19.23	–92.99
135	504.67	–87.5	–675.4	275	884.48	–15.99	–76.39
140	513.33	–85.33	–641.2	280	897.71	–12.68	–59.84
145	522.59	–83.16	–609.0	285	910.91	–9.288	–43.32
150	532.47	–80.97	–578.5	290	924.21	–5.82	–26.83
155	542.97	–78.77	–549.6	295	937.76	–2.274	–10.362
160	554.08	–76.55	–522.2	298.15	946.53	0	0
165	565.79	–74.32	–496.1	300	951.79	1.35	6.082
170	578.07	–72.06	–471.1	305	966.53	5.052	22.51
175	590.91	–69.79	–447.2	310	982.29	8.831	38.91
180	604.26	–67.49	–424.3	315	999.39	12.69	55.28
185	618.09	–65.16	–402.2	320	1018.2	16.62	71.64
190	632.35	–62.81	–380.9	325	1039.3	20.63	87.96
195	646.98	–60.43	–360.3	330	1063	24.71	104.25
200	661.93	–58.02	–340.2	335	1090	28.86	120.51
205	677.14	–55.57	–320.7	340	1121	33.08	136.7
210	692.55	–53.08	–301.6	345	1156.6	37.37	152.8
215	708.08	–50.56	–282.9	350	1197.6	41.73	169
220	723.67	–47.99	–264.6	355	1245.1	46.16	185.1
225	739.26	–45.37	–246.6				

According to the mass loss in each step as mentioned above, a possible mechanism of the thermal decompositions may be described as follows:

$$(C_{20}H_{18}NO_4)_2SO_4\cdot 3H_2O \xrightarrow{319-354K;\ -3H_2O} (C_{20}H_{18}NO_4)_2SO_4$$

and

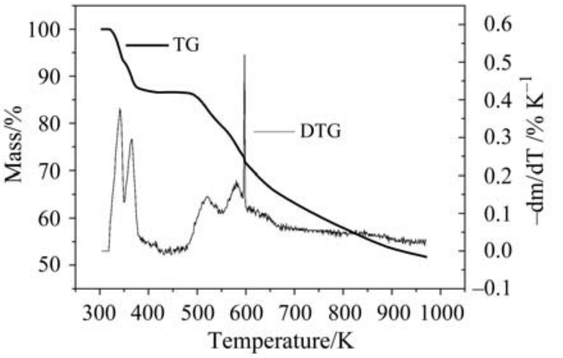

Fig. 2 TG and DTG curves of berberine sulphate under high purity nitrogen

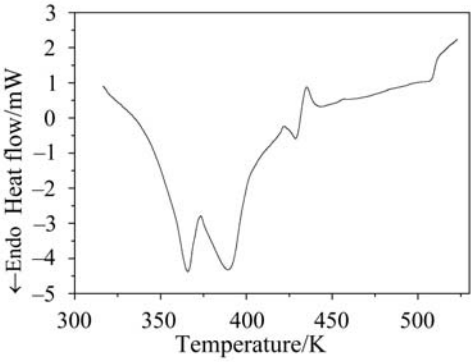

Fig. 3 DSC curve of berberine sulphate under high purity nitrogen

$$(C_{20}H_{18}NO_4)_2SO_4 \xrightarrow{354\text{–}425\ K;\ -2CO} (C_{19}H_{18}NO_3)_2SO_4$$

No further mass loss in the TG curve was observed until $(C_{19}H_{18}NO_3)_2SO_4$ was decomposed at about 480 K. The total mass loss (%) was 48.3% at the temperature of 970 K.

Figure 3 indicates DSC experimental results (repeated in 6 times) of berberine sulphate sample. The first large endothermic peak in Fig. 3 can be ascribed to the loss of crystalline water contained in berberine sulphate sample. The loss of crystalline water started at about 339.3±0.2 K and its peak temperature was corresponding to 365.8±0.6 K. The second large endothermic peak of Fig. 3 can be assigned as decomposing peak of berberine sulphate, which corresponds to a peak temperature of 391.4±0.4 K. Further melting point experiment demonstrated that no melting process of the sample was observed in the whole process. This means that the results obtained with melting point experiment are in good agreement with those obtained by DSC.

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The authors gratefully acknowledge the National Natural Science Foundation of China for financial support to this work under Grant No. 20073047.

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