PCM Measurement Method of Latent Heat and Specific Heat of Phase Change Material

2002 2
DSC, DTA, T-history, Modified T-history.
List of Figures

List of Tables

Nomenclature

1.1 Differential Scanning Calorimetry; DSC .................. 3
1.2 Differential Thermal Analysis; DTA ....................... 6
1.3 Inorganic Analyses ........................................ 8

2. Modified T-history ........................................... 10
  2.1 T-history .................................................. 10
    2.1.1 T-history ........................................... 11
    2.1.2 T-history ........................................... 17
  2.2 Modified T-history ....................................... 18

3.1 Organic Analyses .......................................... 24
3.2 Inorganic Analyses ........................................ 28
3.3 Organic Analyses .......................................... 32
3.4 Inorganic Analyses ........................................ 35
3.5 Inorganic Analyses ........................................ 40
3.6 .......................... 41
3.7 .......................................................... 42
3.8 .......................... 43
3.9 .......................................................... 44
3.10 .......................................................... 48
4 .......................................................... 51
.......................................................... 52
.......................................................... 56
56
1. .......................................................... 57
2. .......................................................... 60
List of Figures

Fig. 1  Heat flux DSC.
Fig. 2  Power compensating DSC.
Fig. 3  Result of DSC(PET).
Fig. 4  The constitution of basic DTA system.
Fig. 5  Result of DTA.
Fig. 6  The measurement methods of latent heat used as heat-flux meter.
Fig. 7  Schematic diagram of experimental system.
Fig. 8  A typical T-history curve of a PCM during a cooling process.
  (with supercooling)
Fig. 9  A typical T-history curve of a PCM during a cooling process.
  (without supercooling)
Fig. 10  A typical T-history curve of a water during a cooling process.
Fig. 11  A typical Modified T-history curve for PCM during a cooling process.
Fig. 12  A typical Modified T-history curve for pure water during a cooling process.
Fig. 13  T-history curve for PCM using CH₃COONa?3H₂O as sample.
Fig. 14  T-history curve for pure water as sample.
Fig. 15  First derivative curve of Fig. 13 to search a point of inflection.
Fig. 16  A Modified T-history curve for Paraffin during a cooling process.
Fig. 17  A Modified T-history curve for pure water during a cooling process.
Fig. 18  First derivative curve of Fig. 16 to search a point of inflection.

Fig. 19  A Modified T-history curve for Lauric acid during a cooling process.

Fig. 20  A Modified T-history curve for pure water during a cooling process.

Fig. 21  First derivative curve of Fig. 19 to search a point of inflection.

Fig. 22  T-history curve for pure water as test material.

Fig. 23  T-history curve for ethylene glycol as reference material.

Fig. 24  First derivative curve of Fig. 22 to search a point of inflection.

Fig. 25  The perpendicular variation of temperature for a CH$_3$COONa·3H$_2$O.

Fig. 26  The perpendicular variation of temperature for a pure water.

Fig. 27  The temperature variation of a radius direction for a CH$_3$COONa·3H$_2$O.

Fig. 28  The temperature variation of a radius direction for a pure water.

Fig. A1  Heat-flux meter.

Fig. A2  Calibration for heat-flux meter.

Fig. A3  Calibration graph for heat-flux meter.

Fig. A4  Section view of test tube.

Fig. A5  Measurement of latent heat.
List of Tables

Table 1  The fusion of heat and specific heat of CH₃COONa·3H₂O
Table 2  The fusion of heat and specific heat of paraffin
Table 3  The fusion of heat and specific heat of Lauric acid
Table 4  The fusion of heat and specific heat of pure water
Table 5  Comparison of results according to the inflection point
Table 6  Results of one-way factorial design
Table 7  Comparison of results according to the $T_f$
Table 8  Comparison of results according to the section of the solid sensible heat
Table 9  Comparison of results according to analysis methods
Table 10  Comparison of $T_m$, $T_s$, $T_i$ and their differences
Table A1  The fusion of heat and specific heat of CH₃COONa·3H₂O obtained using heat-flux meter
Table A2  The fusion of heat and specific heat of pure water obtained using heat-flux meter
Nomenclature

\( A \) : convective area [m\(^2\)]

\( \text{Bi} \) : Biot number, \( hR/(2k) \)

\( C \) : specific heat [kJ/kg·K]

\( H_m \) : latent heat [kJ/kg]

\( h \) : convection of coefficient [W/(m\(^2\)·K)]

\( k \) : thermal conductivity [W/(m·K)]

\( m \) : mass [kg]

\( q'' \) : heat flux [W/m\(^2\)]

\( T \) : temperature [°C]

\( t \) : time [sec]

Superscript

\( ' \) : reference material

Subscript

\( 0 \) : initial state

\( a \) : atmosphere

\( f \) : final point

\( i \) : point of inflection
$l$ : liquid

$m$ : melting point

$p$ : PCM

$s$ : solid

$t$ : tube

$w$ : water
2°C] 改良型 T-history [2]。

Modified T-history [2]。
1.1 Differential Scanning Calorimetry (DSC)

DSC is a technique used to measure the heat flow associated with phase transitions in a material. It is particularly useful for studying materials with small changes in heat capacity. DSC involves comparing the heat flow of a sample with a reference material.

Fig. 1  Heat flux DSC.

Fig. 2  Power compensating DSC.
\[ \frac{dh}{dt} \text{ m·cal/sec} \]

Fig. 1

DSC

Fig. 2

DSC

Fig. 3

DSC

Result of DSC(PET).
DSC

1.  

2.  

3.  

4.  

5.  

DSC

1~10

mg
1.2 Differential Thermal Analysis (DTA)

DTA is a technique used to study the thermal behavior of materials. It involves measuring the temperature difference between two samples as they are subjected to a controlled heating or cooling procedure.

Fig. 4 The constitution of basic DTA system.
Fig. 5 Result of DTA.
1.3 The measurement methods of latent heat used as heat-flux meter.

Fig. 6  The measurement methods of latent heat used as heat-flux meter.
・
34°C で加熱した場合、8 kJ のエネルギーが放出される。これにより、8 kJ のエネルギーが放出される。
(この結果は微生物の活性を示す重要な指標です。)
2. Modified T-history

2.1 T-history

DSC, DTA, ±×·¡ÇÁ·ÎÅÍ DSC, DTA, ±×·¡ÇÁ·ÎÅÍ (1 ~ 10 mg). DSC, DTA, ±×·¡ÇÁ·ÎÅÍ DSC, DTA, ±×·¡ÇÁ·ÎÅÍ, °°Àº PCM. DSC, DTA, ±×·¡ÇÁ·ÎÅÍ DSC, DTA, ±×·¡ÇÁ·ÎÅÍ, ±×·¡ÇÁ·ÎÅÍ Zhang 1999. ±×·¡ÇÁ·ÎÅÍ, ±×·¡ÇÁ·ÎÅÍ. 

°æ¿ì, ÀÌ¿ëÇÏ¿© Àá¿­°ú. ±×·¡ÇÁ·ÎÅÍ, DSC, DTA, ±×·¡ÇÁ·ÎÅÍ. ±×·¡ÇÁ·ÎÅÍ, DSC, DTA, ±×·¡ÇÁ·ÎÅÍ, ±×·¡ÇÁ·ÎÅÍ.
2.1.1 T-history

T-history (Bi < 0.1) is shown in Fig. 7. Fig. 8, Fig. 9, Fig. 10 show T-history for PCM T-history. T-history (Bi = Bi, Ti) is shown in Fig. 8.

Fig. 8 shows PCM T-history. PCM T-history is shown in Fig. 8. PCM T-history is shown in Fig. 8. ?T_m ( = T_m ? T_i) is shown in Fig. 8.

Fig. 9 shows PCM T-history. PCM T-history is shown in Fig. 9. PCM T-history is shown in Fig. 9. ?T_m ( = T_m ? T_i) is shown in Fig. 9.

Fig. 10 shows PCM T-history. PCM T-history is shown in Fig. 10. PCM T-history is shown in Fig. 10. ?T_m ( = T_m ? T_i) is shown in Fig. 10.
Fig. 7 Schematic diagram of experimental system.

Fig. 8 A typical T-history curve of a PCM during a cooling process with supercooling.
Fig. 9  A typical T-history curve of a PCM during a cooling process without supercooling.

Fig. 10  A typical T-history curve of a water during a cooling process.
PCM T-history Fig. 8

\[ (m_1 C_{p,1} + m_p C_{p,d})(T_0 \sim T_s) = h \alpha_p A \]

\[ A_1 = \int_{T_0}^{T_s} dt 

m_1 : \]

\[ m_p : \]

\[ C_{p,d} : \]

\[ C_{p,d} : \]

\[ h : \]

\[ A_c : \]

\[ T_0 : \]

\[ T_s : \]

\[ m_p H_m = h \alpha_p A \]

\[ A_2 = \int_{T_1}^{T_2} dt 

H_m : \]
(m_1 C_{p,s} \pm m_p C_{p,s})(T_s \pm T_r) \pm h A_c A_3 \quad (3)

\[ A_3 \pm \int_{T_{\text{min}}}^{T_{\text{max}}} \left( \frac{d}{dT} \right) \left( T \pm T_{\text{ref}} \right) \, dt \]

C_{p,s} : 

T_r : 

\[ (m_1 C_{p,s} \pm m_w C_{p,w})(T_0 \pm T_s) \pm h A_c A_1' \quad (4) \]

\[ (m_1 C_{p,s} \pm m_p C_{p,w})(T_s \pm T_r) \pm h A_c A_2' \quad (5) \]

\[ A_1' \pm \int_{T_{\text{max}}}^{T_{\text{min}}} \left( \frac{d}{dT} \right) \left( T \pm T_{\text{ref}} \right) \, dt \]

\[ A_2' \pm \int_{T_{\text{min}}}^{T_{\text{max}}} \left( \frac{d}{dT} \right) \left( T \pm T_{\text{ref}} \right) \, dt \]

m_w : 

C_{p,w} : 

Fig. 10
\begin{align*}
C_{p,s} & = \frac{m_w C_{p,w}}{m_p} \frac{m_t C_{p,t}}{A_2} \frac{A_3}{m_p C_{p,t}} \quad (6) \\
C_{p,l} & = \frac{m_w C_{p,w}}{m_p} \frac{m_t C_{p,t}}{A_1} \frac{A_1}{m_p C_{p,t}} \quad (7) \\
H_m & = \frac{m_w C_{p,w}}{m_p} \frac{m_t C_{p,t}}{A_2} \frac{A_2(T_0 ? T_s)}{A_1} \quad (8) \\
H_m & = \frac{m_w C_{p,w}}{m_p} \frac{m_t C_{p,t}}{A_2} \frac{A_2(T_0 ? T_{m,1})}{m_p} \frac{m_t C_{p,w}(T_{m,1} ? T_{m,2})}{m_p} \quad (9)
\end{align*}
2.1.2 T-history

T-history, T-history, T-history, T-history. Fig. 8 shows $t_0 \sim t_1$, $t_1 \sim t_2 \cdots$, $T_1$, $T_2 \cdots$, $t_0 \sim t_1$, $t_1 \sim t_2 \cdots$, $T_1$, $T_2 \cdots$. 

Fig. 8 shows $t_0 \sim t_1$, $t_1 \sim t_2 \cdots$, $T_1$, $T_2 \cdots$. 

PCM, PCM. Fig. 8 shows $t_0 \sim t_1$, $t_1 \sim t_2 \cdots$, $T_1$, $T_2 \cdots$. 

PCM. (1) shows $t_0 \sim t_1$, $t_1 \sim t_2 \cdots$, $T_1$, $T_2 \cdots$. 

[4,5]
2.2 Modified T-history

Modified T-history is shown in Figs. 7 and 11. PCM°C and T-history· are shown in Figs. 12 and 10. Bi (hR/2k, R = PCM°C radius, k = PCM°C conductivity, h = heat transfer coefficient) is 0.1. The solid line and dotted line represent PCM°C and T-history·, respectively.
Fig. 11 A typical Modified T-history curve for PCM during a cooling process.

Fig. 12 A typical Modified T-history curve for pure water during a cooling process.
PCM
ÀÌ
°ú³Ã°¢Çö»óÀ»
ÀÖÀ¸¸é
¾×»ó
Çö¿­±¸°£°ú
Àá¿­±¸°£
»çÀÌÀÇ
°æ°è¸¦
°ú
³Ã°¢ÀÌ
ÇØ¼ÒµÇ´Â
ÁöÁ¡
(1)
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º¼
¼ö
ÀÖ´Ù
. µû¶ó¼­
PCM
ÀÇ
¾×»ó
Çö¿­±¸°£
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10
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)
¿¡
. 10,,
)\(\frac{1}{10}
AhATTCmCm
Cslpptppt

¿©±â¼­,

A_t \ ? \ \int_0^t (T \ ? T_{\cdot a})dt

m_p : PCM
m_{t,p} : PCM
C_{p,j} : PCM
C_{p,j} :
A_c : PCM
T : PCM,
T_{\cdot a} :

m_{t,p} A_c

PCM
ÀÇ
T-history
1
. T-history
\[(m_{t,p} C_{p,t} ? m_{p} C_{p,t})(T_{i} ? T_{f}) ? hA_{c} A_{3}\]  \hspace{1cm} (12)

\[A_{3} ? q_{i}^{j}(T ? T_{a})dt\]

\[T_{f} : \text{as} \text{ as} \text{ as} \text{ as} \text{ as} \text{ as} (T_{a} ? T_{f} ? T_{i})\]

\[m_{w} : \text{as} \text{ as} \text{ as} (\text{as} \text{ as})\]
\[ C_{p,w} : \] 

\[ m_{t,w} : \] 

\[ A'_{c} : \] 

\[ C_{p,l} \frac{m_{t,w} C_{p,l}}{m_{p}} \frac{m_{w} C_{p,w}}{A_{c}} \frac{A_{c}}{A'_{c}} \frac{A_{c}}{A'_{c}} \frac{m_{p}}{m_{p}} C_{p,i} \] 

(16) 

\[ C_{p,s} \frac{m_{t,w} C_{p,l}}{m_{p}} \frac{m_{w} C_{p,w}}{A_{c}} \frac{A_{c}}{A'_{c}} \frac{A_{c}}{A'_{c}} \frac{m_{p}}{m_{p}} C_{p,i} \] 

(17) 

\[ H_{m} \frac{m_{t,w} C_{p,l}}{m_{p}} \frac{m_{w} C_{p,w}}{A_{c}} \frac{A_{c}}{A'_{c}} \frac{A_{c}}{A'_{c}} (T_{m} ? T_{i}) \frac{m_{p}}{m_{p}} C_{p,l} \frac{C_{p,l}}{2} \frac{C_{p,s}}{2} (T_{m} ? T_{i}) \] 

(18)
3.1 Parameters and Conditions

PCM: The temperature of the PCM is maintained at 58°C, which is achieved by circulating a mixture of (CH₃COONa·3H₂O) through the PCM. The temperature is controlled to ensure a constant heat transfer rate.

The heat transfer rates are 0.6 W/m²·K, 4 W/m²·K, and 0 W/m²·K, respectively. The Bi number is less than 0.1.

The thickness of the PCM is varied from 0.5 cm to 10 cm, 20 cm. The heat transfer coefficients are typical of PCM applications. The flow rate is maintained at 0.1 m/s.

Fig. 13, Fig. 14, Fig. 15, T-history
Fig. 13  T-history curve for PCM using $\text{CH}_3\text{COONa}\cdot 3\text{H}_2\text{O}$ as sample.

Fig. 14  T-history curve for pure water as sample.
Fig. 15  First derivative curve of Fig. 13 to search a point of inflection.

Table 1  The fusion of heat and specific heat of CH₃COONa?3H₂O

<table>
<thead>
<tr>
<th>Sample</th>
<th>$C_{p,l}$</th>
<th>$C_{p,s}$</th>
<th>$H_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.86</td>
<td>2.17</td>
<td>262</td>
</tr>
<tr>
<td>2</td>
<td>3.35</td>
<td>2.19</td>
<td>242</td>
</tr>
<tr>
<td>3</td>
<td>3.71</td>
<td>2.42</td>
<td>237</td>
</tr>
<tr>
<td>4</td>
<td>4.29</td>
<td>2.29</td>
<td>242</td>
</tr>
<tr>
<td>5</td>
<td>3.93</td>
<td>2.44</td>
<td>240</td>
</tr>
<tr>
<td>6</td>
<td>4.29</td>
<td>2.22</td>
<td>244</td>
</tr>
<tr>
<td>Average</td>
<td>3.74 ± 0.59</td>
<td>2.26 ± 0.13</td>
<td>245 ± 9</td>
</tr>
<tr>
<td>DSC</td>
<td>-</td>
<td>-</td>
<td>253</td>
</tr>
<tr>
<td>Reference value[6]</td>
<td>3.05</td>
<td>-</td>
<td>226</td>
</tr>
<tr>
<td>Reference value[7]</td>
<td>3.68</td>
<td>2.11</td>
<td>263</td>
</tr>
</tbody>
</table>
Table 1  

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified T-history</td>
<td>226 ~ 263 [kJ/kg]</td>
</tr>
<tr>
<td>DSC</td>
<td>245 ± 95%</td>
</tr>
</tbody>
</table>

...
Fig. 16  A Modified T-history curve for Paraffin during a cooling process.
(\(T_s, T_m\))
Fig. 17  A Modified T-history curve for pure water during a cooling process.

Fig. 18  First derivative curve of Fig. 16 to search a point of inflection.
Table 2  The fusion of heat and specific heat of paraffin

<table>
<thead>
<tr>
<th>Sample</th>
<th>$C_{p,f}$</th>
<th>$C_{p,s}$</th>
<th>$H_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.89</td>
<td>5.50</td>
<td>141</td>
</tr>
<tr>
<td>2</td>
<td>2.83</td>
<td>5.09</td>
<td>127</td>
</tr>
<tr>
<td>3</td>
<td>1.79</td>
<td>5.96</td>
<td>126</td>
</tr>
<tr>
<td>4</td>
<td>2.35</td>
<td>4.75</td>
<td>143</td>
</tr>
<tr>
<td>5</td>
<td>2.50</td>
<td>4.88</td>
<td>138</td>
</tr>
<tr>
<td>6</td>
<td>1.75</td>
<td>4.49</td>
<td>132</td>
</tr>
<tr>
<td>Average</td>
<td>2.19 ± 0.19</td>
<td>5.11 ± 0.56</td>
<td>135 ± 8</td>
</tr>
<tr>
<td>DSC</td>
<td>-</td>
<td>-</td>
<td>130</td>
</tr>
<tr>
<td>Reference value[8]</td>
<td>-</td>
<td>-</td>
<td>156.8</td>
</tr>
</tbody>
</table>

44°C, Fig. 16 T-history. The graph shows the temperature changes with time. Table 2 lists the fusion of heat and specific heat of paraffin for different samples.

Table 2 also shows the DSC values, which are 130 [kJ/kg] with a 95% confidence interval. The reference value is 156.8 [kJ/kg].
3.3 A Modified T-history curve for Lauric acid during a cooling process.

Fig. 19 A Modified T-history curve for Lauric acid during a cooling process.
Fig. 20  A Modified T-history curve for pure water during a cooling process.

Fig. 21  First derivative curve of Fig. 19 to search a point of inflection.
<table>
<thead>
<tr>
<th>Sample</th>
<th>$C_{p,i}$</th>
<th>$C_{p,s}$</th>
<th>$H_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.16</td>
<td>3.01</td>
<td>171</td>
</tr>
<tr>
<td>2</td>
<td>2.10</td>
<td>1.98</td>
<td>191</td>
</tr>
<tr>
<td>3</td>
<td>1.93</td>
<td>2.50</td>
<td>192</td>
</tr>
<tr>
<td>4</td>
<td>2.45</td>
<td>3.70</td>
<td>186</td>
</tr>
<tr>
<td>5</td>
<td>2.16</td>
<td>2.81</td>
<td>197</td>
</tr>
<tr>
<td>6</td>
<td>2.17</td>
<td>2.85</td>
<td>184</td>
</tr>
<tr>
<td>Average</td>
<td>2.14 ± 0.46</td>
<td>2.81 ± 0.60</td>
<td>186 ± 10</td>
</tr>
</tbody>
</table>

DSC - - 179

Reference value[8] - 177

Reference value[9] 2.38 1.80 183

3.9% 

186±10 [kJ/kg] 

DSC 179 [kJ/kg] 

3.9% 

34
3.4 分类及数据

根据分类和数据的分析，我们可以看到在0°C、-10°C和-11.5°C情况下，温度历史的变化情况。Fig. 22 23 24 分别展示了这些温度历史的变化。Fig. 24 也提供了6 mm的数据情况。

Fig. 24

95% 327±12 [kJ/kg] 335 [kJ/kg] 2.4%
Fig. 22  T-history curve for pure water as test material.

Fig. 23  T-history curve for ethylene glycol as reference material.
Fig. 24  First derivative curve of Fig. 22 to search a point of inflection.

Table 4  The fusion of heat and specific heat of pure water

<table>
<thead>
<tr>
<th>Sample</th>
<th>$C_{p,l}$</th>
<th>$C_{p,s}$</th>
<th>$H_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.39</td>
<td>1.56</td>
<td>316</td>
</tr>
<tr>
<td>2</td>
<td>3.99</td>
<td>1.54</td>
<td>323</td>
</tr>
<tr>
<td>3</td>
<td>4.55</td>
<td>1.31</td>
<td>320</td>
</tr>
<tr>
<td>4</td>
<td>4.90</td>
<td>1.55</td>
<td>319</td>
</tr>
<tr>
<td>5</td>
<td>4.76</td>
<td>2.42</td>
<td>335</td>
</tr>
<tr>
<td>6</td>
<td>4.89</td>
<td>2.33</td>
<td>346</td>
</tr>
<tr>
<td>Average</td>
<td>4.58 ± 0.37</td>
<td>1.79 ± 0.49</td>
<td>327 ± 12</td>
</tr>
</tbody>
</table>

Reference [10,11]  4.18  2.09  335
3.5 闵行历史

Modified T-history 与 T-history 之间存在一定的差异，具体表现如下。表 5 为不同转折点的比较结果。

表 5 根据不同转折点的比较结果

<table>
<thead>
<tr>
<th>Sample</th>
<th>$C_{p,s}$ ± sensitivity (%/°C)</th>
<th>$H_m$ ± sensitivity (%/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.15 ± 2.0</td>
<td>262 ± 3.1</td>
</tr>
<tr>
<td>2</td>
<td>2.22 ± 2.6</td>
<td>241 ± 2.5</td>
</tr>
<tr>
<td>3</td>
<td>2.33 ± 0.7</td>
<td>242 ± 0.5</td>
</tr>
<tr>
<td>4</td>
<td>2.45 ± 0.4</td>
<td>237 ± 0.6</td>
</tr>
<tr>
<td>5</td>
<td>2.48 ± 4.7</td>
<td>240 ± 0.4</td>
</tr>
<tr>
<td>6</td>
<td>2.16 ± 0.9</td>
<td>232 ± 1.5</td>
</tr>
</tbody>
</table>
3.6 Results of one-way factorial design

Table 6 Results of one-way factorial design

<table>
<thead>
<tr>
<th>Sample</th>
<th>$F_0$</th>
<th>Rejection value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_3$COONa?3H$_2$O</td>
<td>0.48</td>
<td>19.16</td>
</tr>
<tr>
<td>Paraffin</td>
<td>0.83</td>
<td>225</td>
</tr>
<tr>
<td>Lauric acid</td>
<td>1.97</td>
<td>19</td>
</tr>
<tr>
<td>Pure water</td>
<td>1.06</td>
<td>225</td>
</tr>
</tbody>
</table>
3.7 Modified T-history

Modified T-history $T_f$, $T_{i,a}$, $T_r$, and $T_i$. $T_f$ is the temperature at which the reaction occurs. $T_{i,a}$ is the initial temperature. $T_r$ is the reaction temperature. $T_i$ is the initial reaction temperature.

Table 7  Comparison of results according to the $T_f$

<table>
<thead>
<tr>
<th>Sample</th>
<th>$C_{p,s}$</th>
<th>$H_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.15 ? 0.02</td>
<td>262 ? 0.0</td>
</tr>
<tr>
<td>2</td>
<td>2.22 ? 0.02</td>
<td>241 ? 0.0</td>
</tr>
<tr>
<td>3</td>
<td>2.33 ? 0.03</td>
<td>242 ? 0.4</td>
</tr>
<tr>
<td>4</td>
<td>2.45 ? 0.02</td>
<td>237 ? 0.5</td>
</tr>
<tr>
<td>5</td>
<td>2.48 ? 0.03</td>
<td>240 ? 0.5</td>
</tr>
<tr>
<td>6</td>
<td>2.16 ? 0.02</td>
<td>232 ? 0.0</td>
</tr>
</tbody>
</table>
3.8 \text{ Modified } T\text{-history} \quad T_i \sim T_f \quad \text{ and } \quad T_j \sim T_f \quad \text{ and } \quad T_k \sim T_f

\text{ Table 8: Comparison of results according to the section of the solid sensible heat}

<table>
<thead>
<tr>
<th>Sample</th>
<th>$C_{p,s}$</th>
<th>$H_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.21 ? 0.03</td>
<td>261 ? 0.9</td>
</tr>
<tr>
<td>2</td>
<td>2.06 ? 0.12</td>
<td>242 ? 0.9</td>
</tr>
<tr>
<td>3</td>
<td>2.21 ? 0.08</td>
<td>237 ? 0.6</td>
</tr>
<tr>
<td>4</td>
<td>2.36 ? 0.07</td>
<td>243 ? 0.7</td>
</tr>
<tr>
<td>5</td>
<td>2.28 ? 0.12</td>
<td>241 ? 0.6</td>
</tr>
<tr>
<td>6</td>
<td>2.23 ? 0.10</td>
<td>232 ? 0.6</td>
</tr>
</tbody>
</table>
3.9 

T-history Bi 0.1. Bi<0.1

$\frac{4 \text{ W/m}^2 \cdot \text{K}}{0.8 \text{ cm}}$ PE pipe($\frac{0.52 \text{ W/m} \cdot \text{K}}{10 \text{ cm}}$ to $25 \text{ cm}$).

Fig. 25 The perpendicular variation of temperature for a CH$_3$COONa·

3H$_2$O.
Fig. 26  The perpendicular variation of temperature for a pure water.

Fig. 27  The temperature variation of a radius direction for a \( \text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O} \).
Fig. 28  The temperature variation of a radius direction for a pure water.
### 3.10 Analysis of T-history

#### Analysis I

40% of the T-history data is shown in Table 9. The percentage of $H_m$ in T-history is shown in Table 10.

$T \sim e^{t^2}$

$T_i \sim 3.3°C$

$T_m \sim 3.3°C$
Table 9  Comparison of results according to analysis methods

\[
\begin{array}{|c|ccc|}
\hline
& C_{p,l} & C_{p,s} & H_m \\
\hline
T-history & 3.41 \pm 0.59 & 1.98 \pm 0.45 & 408 \pm 27 \\
Modified T-history & 3.77 \pm 0.57 & 2.25 \pm 0.24 & 245 \pm 9 \\
Analysis I & 3.74 \pm 0.60 & 2.35 \pm 0.20 & 236 \pm 11 \\
Analysis II & 3.40 \pm 0.60 & 1.53 \pm 0.44 & 423 \pm 33 \\
\hline
Reference value & 3.05 & - & 226 \\
Reference value & 3.68 & 2.11 & 263 \\
Value of DSC & - & - & 253 \\
\hline
\end{array}
\]

Analysis I : including the effect of sensible heat in the range of latent heat release

Analysis II : using an inflection point in T-history method to determine the range of latent heat release

Table 10  Comparison of $T_m$, $T_s$, $T_i$ and their differences

\[
\begin{array}{|c|cccc|}
\hline
No. & T_m & T_s & T_i & T_m \text{ vs} \ T_i & T_s \text{ vs} \ T_i \\
\hline
1 & 58.1 & 46.6 & 43.8 & 14.3 & 2.8 \\
2 & 57.8 & 48.2 & 46.8 & 11.0 & 1.4 \\
3 & 58.1 & 48.3 & 42.5 & 15.6 & 5.8 \\
4 & 58.0 & 48.3 & 41.1 & 16.9 & 7.2 \\
5 & 57.9 & 47.2 & 44.4 & 13.5 & 2.8 \\
6 & 58.1 & 45.3 & 45.7 & 12.4 & -0.4 \\
\hline
Average & 58.0 \pm 0.1 & 47.3 \pm 1.3 & 44.1 \pm 2.2 & 14.0 \pm 2.2 & 3.3 \pm 2.9 \\
\hline
\end{array}
\]


50


Modified T-history

$T_i$, $T_{\gamma,a}$...
[1] Zhang, Y. and Jiang, Y., 1999, A simple method, the T-history method, of
determining the heat of fusion, specific heat and thermal conductivity of
201-205.

Thermal Energy Storage Capsule in the Heat Removal Process, Using an


on the Measurement Method of Fusion and Specific Heat of PCMs used as the
Conference.

history method used as Measurement Method of Heat of Fusion and Specific
Heat of PCMs, SAREK.


trihydrate for solar latent heat storage, controlling the melting point, Solar


Abstract

Measurement Method of Latent Heat and Specific Heat of Phase Change Material

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Dept. of Mechanical Engineering
The Graduate School
Kyung Hee Univ., Korea

In order to evaluate the performance of thermal storage material, studies on the measurement methods of latent heat and specific heat have been performed. So far, DSC, DTA, T-history methods have been used to measure the thermal properties. But thermal analysis methods such as DSC and DTA can represent a part of materials because the amount of test material is very small. T-history method has a great advantage in obtaining in measuring heat of fusion, inhomogeneously consisting of several components other than simple experimental apparatus and no necessity taking samples. However, irrationality in selecting the range of latent heat release and neglecting the effect of sensible heat in this range can make the accuracy of heat of fusion worse. In the present study, we propose a reasonable method modifying the original T-history method. Also we will be proposed to modified T-history
method analyzing for solve the program. In addition it clears up a final
temperature obscuring in T-history method, it measures the heat of fusion in
regions of the solid sensible heat and so is available to ignore amount within
1%. As it analyzed sample with being supercooling and less supercooling,
Modified T-history method raised degrees of accuracy.
(a) component of heat-flux meter.

(b) concept of heat-flux meter.

Fig. A1 Heat-flux meter.
1. Heat-flux meter

Heat-flux meter (heat-flux meter) and silicon (thermopile) are used.[13]

Fig. A1: A and B: Heat-flux meter. Fig. A1(a): Fig. A2: Calibration for heat-flux meter.

Fig. A2: Calibration for heat-flux meter.
(thermal grease)

Fig. A2  (wrap)
\[ q A \frac{dT}{dx} = k A \frac{T}{x} \]  \hspace{1cm} (A1)

\[ ? T = C_1 ? E \]  \hspace{1cm} (A2)

\[ q'' A \frac{k C_1}{x} ? E \]  \hspace{1cm} (A3)

\[ q'' ? 1014.6 ? E \]  \hspace{1cm} (A4)
2. 

2.1 

Fig. A4  Section view of test tube.

- polyethylene tube
- heat-flux meter
- wrap, tape
- polyethylene cap
- •: location of thermocouple
- (thermal grease)
- (wrap)

Fig. A5

Fig. 5A(b)
\[ C_{p,l} = \frac{A A_i}{m_p (T_1 - T_2)} \]  \hspace{1cm} (A5)

\[ C_{p,s} = \frac{A A_4}{m_p (T_3 - T_4)} \]  \hspace{1cm} (A6)

\[ H_m = \frac{A A_2}{m_p} \]  \hspace{1cm} (A7)

\[ \begin{align*}
A : & \\
m_p : & \\
A_1 : & \\
A_2 : & \\
A_3 : & \\
A_4 : & \\
\end{align*} \]
(a) Timewise variation of heat flux and temperatures.

(b) Simplified figure.

Fig. A5 Measurement of latent heat.
### 2.2 Results

According to Table A1, the DSC results show that the thermal transition of the sample occurs at 246±3 [kJ/kg]. This indicates a 2.7% decrease in energy. The standard deviation is 5.02±0.3 [kJ/kg °C], and the average is 5.30±1.7 [kJ/kg °C].

Table A1: | T-history | 346±4 [kJ/kg] | 6.2% decrease | 4.15±0.2 [kJ/kg °C] | 6.04±0.6 [kJ/kg °C]
|---|---|---|---|---|

Table A2: | T-history | 335 [kJ/kg] | 6.2% decrease | 4.15±0.2 [kJ/kg °C] | 6.04±0.6 [kJ/kg °C]
Table A1  The fusion of heat and specific heat of CH₃COONa·3H₂O obtained using heat-flux meter

<table>
<thead>
<tr>
<th>Sample</th>
<th>( C_{p,l} )</th>
<th>( C_{p,s} )</th>
<th>( H_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.00</td>
<td>7.00</td>
<td>241</td>
</tr>
<tr>
<td>2</td>
<td>5.87</td>
<td>5.78</td>
<td>247</td>
</tr>
<tr>
<td>3</td>
<td>4.33</td>
<td>3.45</td>
<td>242</td>
</tr>
<tr>
<td>4</td>
<td>5.25</td>
<td>4.39</td>
<td>249</td>
</tr>
<tr>
<td>5</td>
<td>4.49</td>
<td>3.85</td>
<td>236</td>
</tr>
<tr>
<td>6</td>
<td>4.18</td>
<td>7.43</td>
<td>258</td>
</tr>
<tr>
<td>Average</td>
<td>5.02 ± 0.30</td>
<td>5.30 ± 1.70</td>
<td>246 ± 3</td>
</tr>
<tr>
<td>DSC</td>
<td></td>
<td></td>
<td>253</td>
</tr>
</tbody>
</table>

Table A2  The fusion of heat and specific heat of pure water obtained using heat-flux meter

<table>
<thead>
<tr>
<th>Sample</th>
<th>( C_{p,l} )</th>
<th>( C_{p,s} )</th>
<th>( H_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.80</td>
<td>7.10</td>
<td>352</td>
</tr>
<tr>
<td>2</td>
<td>4.14</td>
<td>6.25</td>
<td>355</td>
</tr>
<tr>
<td>3</td>
<td>4.16</td>
<td>5.72</td>
<td>355</td>
</tr>
<tr>
<td>4</td>
<td>4.41</td>
<td>6.02</td>
<td>354</td>
</tr>
<tr>
<td>5</td>
<td>4.29</td>
<td>5.65</td>
<td>356</td>
</tr>
<tr>
<td>6</td>
<td>4.13</td>
<td>5.50</td>
<td>364</td>
</tr>
<tr>
<td>Average</td>
<td>4.15 ± 0.20</td>
<td>6.04 ± 0.60</td>
<td>356 ± 4</td>
</tr>
<tr>
<td>Reference[10,11]</td>
<td>4.18</td>
<td>2.09</td>
<td>335</td>
</tr>
</tbody>
</table>