



# Experimental study of the cooling process of partially-melted sodium acetate trihydrate



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## ABSTRACT

Actual phase transition processes of phase change materials (PCMs) are not fully isothermal. Furthermore, PCMs may exist in the partially-melted states during their applications. In this paper, the cooling processes of sodium acetate trihydrate (SAT), starting from three different states, namely not-melted, partially-melted, and fully-melted, were studied. It was found that the original state of SAT prior to phase transition affected its performance. When SAT was in the partially-melted state and the melting ratio was low, SAT released latent heat during the cooling process and the degree of supercooling was relatively small. When the melting ratio of SAT was high or the PCM was in its fully-melted state, the degree of supercooling was high and it did not release latent heat. The results also showed that the degree of supercooling of partially-melted SAT increased with the increase of maximum heating temperature sustained time prior to the cooling process.

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## 1. Introduction

Because of their high thermal storage density, latent heat storage systems that use phase change materials (PCMs) are being used in many fields, including buildings, as in the case of improving the thermal performance of building enclosures, solar energy storage, and supplying free cooling and reducing energy consumption [1–6].

In theory, the phase transition process of PCMs is always considered to be isothermal or nearly isothermal. However, actual PCMs have their own phase change temperature ranges, which in some cases may be more than 10 °C [7–9]. Fig. 1 shows the relationship between temperature and heat absorbed for ideal and actual PCMs. As shown in the figure, actual phase transition processes are non-isothermal.

Based on the phase change temperature range of PCM, three different states of any PCM can be identified as (1) when the PCM temperature is lower than its starting melting temperature, it is deemed to be in the not-melted state; (2) when the PCM temperature is higher than its ending melting temperature, it is deemed to be in the fully-melted state; and (3) when the PCM temperature is between its starting melting temperature and its ending

melting temperature, it is deemed to be in the partially-melted state. For storing the most thermal energy, it is recommended that the PCM starts the phase transition process from its solid state (not-melted state) and ends in its fully-melted state. However, because of several factors, a PCM may not always reach its fully-melted state or may start a new cycle under a non-solid state. For example, when a PCM is integrated into the enclosure of a building [10–13], if the outdoor was cloudy or the ambient air temperature was low, the PCM may not absorb sufficient heat and it may remain in a partially-melted state during the daytime. Because partially-melted states are common during the applications of PCMs, it is important to understand the phase transition processes of partially-melted PCMs and to evaluate the differences between partially-melted PCMs and fully-melted PCMs.

Based on the situation described above, a kind of salt hydrate PCMs, known as sodium acetate trihydrate (SAT), was selected to study the phase change characteristics of partially-melted states via differential scanning calorimeter (DSC) [14]. SAT has a natural tendency to supercool during its solidification process [15–19], which affects its application. However, it was found that if SAT were cooled down from a partially-melted state, it would release latent heat and quickly solidify without adding any nucleating agents [14].

Because the size of the sample in a DSC test is rather small and the heating and cooling rates are linear, further investigation was needed to learn if actual phase transition conditions were similar

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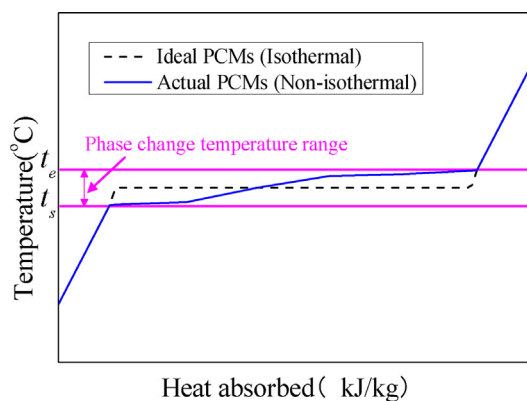


Fig. 1. Relationship between temperature and heat absorbed for ideal and actual PCMs.  $t_s$ : starting melting temperature;  $t_e$ : ending melting temperature.

to DSC testing conditions. Therefore, in this paper, the cooling processes of SAT in different states under environmental conditions were studied and analyzed.

## 2. Material and experimental set-up

The SAT used in this study was analytically pure. As shown in the Fig. 1(a) in [14], upon heating, SAT starts to melt at about 59.0 °C. The maximum heat flow point occurs at a temperature of about 63.0 °C, which yields a calculated latent heat of fusion of 257.2 kJ/kg with a melting temperature range of 58.9–67.3 °C.

The experimental set-up was consisted of several calibrated test tubes, filled with either SAT or water, placed inside a temperature controlled water bath. A scientific digital scale was used to accurately measure each sample before it was placed inside a calibrated test tube. In every experiment, two test tubes, one with 8 g of SAT and the other with 10 ml of water, were placed inside the temperature controlled water bath and heated for a period of time. After a heating process, the test tubes were then taken out of the water bath where they were allowed to cool down under ambient conditions. Thermocouples with a maximum error of 0.1 °C were used to measure the temperatures of SAT and water samples. Relevant phase change characteristics, such as the amount of heat release, duration of heat release, and degree of supercooling were obtained via cooling curves of SAT.

Calibration tests were performed prior to each test to ensure that any two test tubes would produce accurate results and to establish baselines. That is, test tubes with the same volume water were heated in the temperature controlled water bath and then allowed to cool down under ambient conditions. Fig. 2 shows the calibration test results. As shown in the figure, the cooling curves of the test tubes were nearly identical, which set the thermal performance baseline for the tests.

## 3. Results and discussions

Three states for SAT were identified and used in the analyses: the not-melted state, the partially-melted state, and the fully-melted state. To compare the phase transition performances of SAT for these states, a number of experiments were conducted, which mainly differed according to the maximum heating temperatures (i.e., the controlled temperatures of water bath).

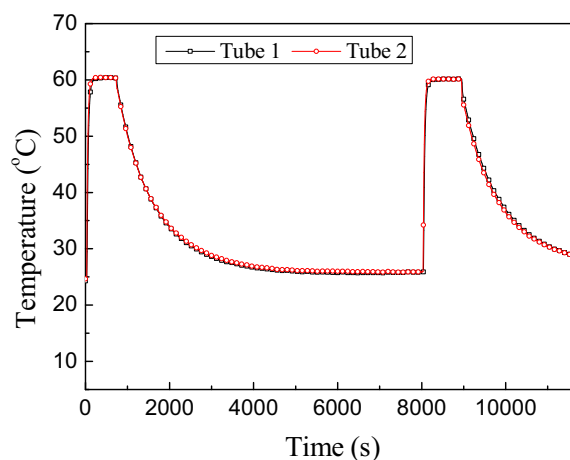


Fig. 2. Calibration results using water in two identical test tubes.

### 3.1. Effects of maximum heating temperature on the cooling process of SAT

Fig. 3 shows the cooling curves of SAT and water for several maximum heating temperatures. Fig. 4 shows the corresponding photographs of the test tubes containing SAT during the cooling processes. In these experiments, the test tubes with SAT and water were placed into the temperature controlled water bath and heated for 50 min. The selected maximum heating temperatures were 55.0 °C, 58.0 °C, 59.0 °C, 60.0 °C, 61.0 °C, 62.0 °C, 63.0 °C, 64.0 °C, 65.0 °C, and 70.0 °C, respectively. The maximum temperature of SAT during heating process in every experiment is shown in Table 1.

From Figs. 3(a) and 4(a), which were generated and photographed, respectively, upon heating to and cooling down from a maximum heating temperature of 55.0 °C, it was observed that the SAT did not melt, and as a result, there was no latent heat released during the cooling process. Furthermore, the variations of the temperature of SAT showed that its temperature dropped at a faster rate than the temperature of water. The reason for this was that 55.0 °C was lower than the starting melting temperature of the SAT. The photographs of Fig. 4(a) clearly show that there was no phase change during the cooling process of the PCM. This situation was considered to be in the not-melted state.

From Fig. 3(b)–(f), when the maximum heating temperatures were between 58.0 °C and 62.0 °C, it was observed that the SAT released increasing amounts of stored heat as the maximum heating temperatures increased. When the maximum heating temperatures were between 59.0 °C and 62.0 °C and after sustaining the maximum heating temperature for 50 min, SAT disassociated itself into two parts: one part was an aqueous solution, while the lower part was mainly a concentration of sodium acetate. When the test tube was exposed to ambient air outside the water bath, the SAT released the latent heat it had absorbed during melting, and as a result, it solidified. After several minutes, and after the SAT had released the entire latent heat, as shown in Fig. 4(c)–(f), no further changes were observed during the remaining of the cooling process. According to the definition, the SAT in these experiments was considered to be in the partially-melted state. In this range, the melting ratios were low.

As shown in Fig. 3(g)–(j), when the maximum heating temperatures were 63.0 °C, 64.0 °C, 65.0 °C and 70.0 °C, and similar to the preceding experiments, the SAT absorbed latent heat during the first thermal cycle, so its rate of temperature increase was lower than that of the water. That is, the SAT temperature curve was lower than the water temperature curve during the heating process.

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