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USE OF PHASE CHANGE MATERIALS FOR FROST PROTECTION APPLICATIONS

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Abstract

Transportation and infrastructure sectors face difficulties during the winter season. When road's temperature drops below 3°C, the risk of ice formation increases, leading to reduced traction and snow accumulation. The use of phase change materials (PCMs) can be a potential solution. However, it is important to consider various factors when selecting PCMs, including phase change temperature, latent heat, and long-term stability. In this study, our focus was on RT5HC, a paraffin with a melting temperature of 5°C. Various thermal analysis techniques were employed to characterize its thermophysical properties, particularly its thermal stability and latent heat. The results of the study demonstrated that the RT5HC paraffin reveals good thermal stability for the intended application. Moreover, its high latent heat provides an advantage for thermal energy storage. These findings contribute to advancements in the field of PCMs and offer promising prospects for their use in preventing ice formation and freezing during winter periods.

Keywords:

Phase change materials, Paraffin, Heat storage

1 INTRODUCTION

With the global population continuously growing, there is an increasing demand for energy worldwide. However, we are confronted with the depletion of finite resources and the escalating impacts of climate change. Facing with this situation, it is necessary to look for sustainable and long-term solutions. Currently, our primary energy sources heavily rely on finite fossil fuels, which present significant challenges due to their high carbon dioxide emissions [1].

In the field of transportation and infrastructure, the winter season brings particular situations. When the temperature of roads or runways drops below the critical threshold of 3°C, the risk of ice formation increases, leading to concerns about reduced traction and snow accumulation. This issue has detrimental effects on the environment, as it necessitates more frequent use of salt operations during winter. To prevent ice formation and ground freezing, the use of phase change materials (PCMs) is a possible option [2].

Apart from considering the phase transition temperature and latent heat, other factors such as long-term stability, phase segregation, and supercooling issues are considered. Organic PCMs have been chosen for this study [3]. In this paper, we conducted a study to characterize the RT5HC paraffin, which has a melting temperature of 5°C. Through various thermal analysis techniques, we aimed to determine its temperature, phase change enthalpy, and degradation temperature.

The ultimate goal is to incorporate these materials into heat exchangers to prevent ice formation on pedestrian.

2 MATERIALS AND METHODS

2.1 Materials

In this investigation, we used RubiTherm RT5HC paraffin, a commercially available product with a specified phase change temperature of 5°C.

2.2 Thermogravimetric analysis TGA

The thermogravimetric analysis (TGA 4000 from Perkin Elmer) was used to study the mass loss of RT5HC as a function of temperature. Measurements were performed under controlled air conditions with a flow rate of 20 mL/min, using a heating rate of 3°C/min over a temperature range of 30°C to 650°C.

2.3 Differential scanning calorimetry DSC

The enthalpy was determined to an accuracy of $\pm 2\%$ and the temperature to an accuracy of $\pm 0.1^\circ\text{C}$ using differential scanning calorimetry (DSC 6000 from Perkin Elmer). The instrument was calibrated using pure water, indium and tin as reference materials. The measurements were performed at a heating rate of $10^\circ\text{C}/\text{min}$.

The measurement of the specific heat capacity of paraffin was performed by analyzing an empty unsealed sample pan, pure sapphire and the sample within the same temperature range, with a 5 minutes isothermal

period at the beginning and the end of the heating process at 0,5°C/min.

2.4 Density measurements

The density of RT5HC paraffin was determined using a pycnometer and a precision balance (0,00001g). The pycnometer was first filled with distilled water to measure its filled mass, then filled with liquid paraffin (RT5HC) to obtain a new mass measurement.

3 RESULTS AND DISCUSSION

3.1 Thermal stability

Figure 1 illustrates the weight loss of RT5HC. It can be observed that the weight loss is negligible at temperatures below 60°C. However, above this threshold, a sharp decrease in paraffin mass is observed until the complete degradation of RT5HC.

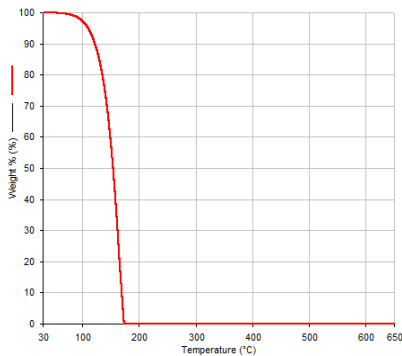


Fig. 1 : Thermal degradation of paraffin RT5HC

3.2 DSC data analysis

RT5HC paraffin is submitted to two thermal cycles at a rate of 10°C/min. Figures 2 and 3 illustrate the DSC curves of the second thermal cycle. The two figures show that the DSC curve of the RT5HC paraffin exhibits a peak during the heating and cooling processes, indicating the solid-liquid and liquid-solid phase transitions, respectively.

Analysis of these curves reveals that the latent heats of melting and crystallization of RT5HC are 239.7 J/g and 236.9 J/g, respectively. Melting occurs at a temperature of 6.41°C, while crystallization occurs at a temperature of 0.07°C.

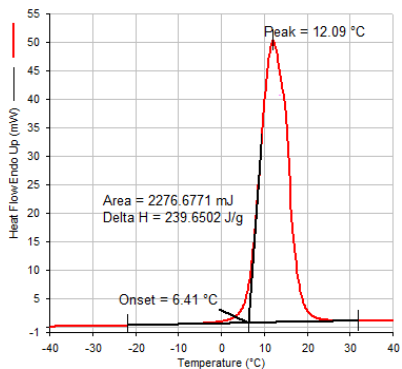


Fig. 2 : Thermogram of RT5HC (heating)

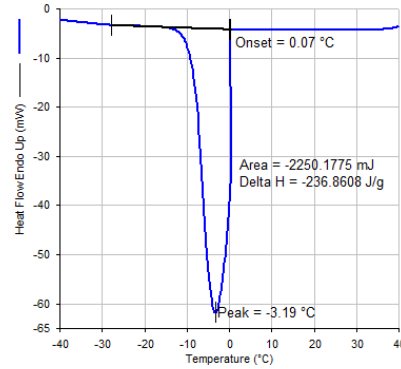


Fig. 3 : Thermogram of RT5HC (cooling)

The DSC measurements revealed a significant difference between the crystallization temperature and the melting temperature, indicating a pronounced supercooling effect. This phenomenon is commonly observed in PCMs and may be attributed to factors such as the small size and limited nucleation sites. However, it is important to note that the supercooling can be reduced by increasing the sample size and employing slower cooling rates [4].

These results are in line with winter protection applications. The exothermic nature of the crystallization prevents the water from freezing on the road.

The evolution of specific heat of the RT5HC has been determined according to the following equation [5]:

$$Cp_{PCM}(T) = \frac{\left(\frac{dH}{dT}\right)_{PCM} \cdot m_{saphir} \cdot Cp_{saphir}}{\left(\frac{dH}{dT}\right)_{saphir} \cdot m_{PCM}}$$

$$Cp_{saphir}(T) = -6,1428 \cdot 10^{-6} \cdot T^2 + 0,0024 \cdot T + 0,7173$$

Figure 4 illustrates the variation of the specific heat as a function of temperature, we note that the specific heat of RT5HC in the solid and liquid state increases with temperature.

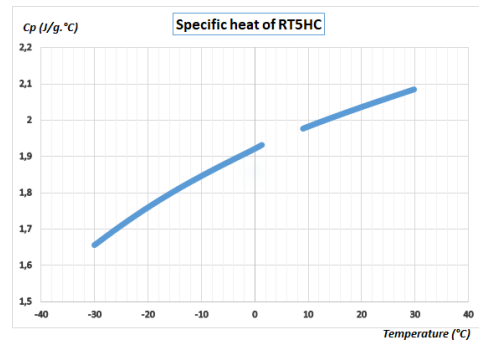


Fig. 4 : Evolution of the specific heat capacity of RT5HC with temperature

3.3 Density measurements

The density of RT5HC was determined at 25°C using the following equations [5] where m₀ is the weight of the empty pycnometer, m₁ is the weight of the pycnometer filled with distilled water and m₂ is the weight of the pycnometer filled with paraffin.

$$d = \frac{\rho(\text{paraffine})}{\rho(\text{eau})} \tag{1}$$

$$d = \frac{m_2 - m_0}{m_1 - m_0} \quad (2)$$

the result is presented in table 1.

Table 1: Density of liquid paraffin RT5HC

PCM	d measured at 25°C	d theoretical at 15°C
RT5HC	0,76	0,76

4. CONCLUSION

Phase change materials (PCMs) are widely used in various industrial and technical fields. Recent work has been undertaken to explore their use at low temperatures, specifically in the context of winter maintenance. In this context, their primary role is to maintain the local pavement temperature above the dew point temperature, preventing water condensation and freezing.

The analysis of the thermophysical properties of the paraffin revealed that RT5HC exhibits good thermal stability for the intended application. Furthermore, the DSC study demonstrated that the RT5HC paraffin has a high latent heat, providing an advantage for thermal energy storage.

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