

THE CAPRIC-LAURIC ACID AND PENTADECANE COMBINATION AS PHASE CHANGE MATERIAL FOR LOW-TEMPERATURE THERMAL ENERGY STORAGE

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Abstract

The results obtained from the assessment of the mixture of capric acid and lauric acid (C-L acid), in the respective composition ratio of 65 and 35 by mole percent, proved acceptable as good phase change material (PCM) for thermal energy storage (TES). However, the C-L acid temperature incursion (18-20°C) was quite high for low-temperature TES. Previous work has indicated that multiple PCM provides a thermodynamic advantage for latent TES. With the thermal property qualifications offered by pentadecane (163 kJ/kg, latent heat and 9.9°C, melting temperature), the thermal characteristic of the combination of pentadecane with the C-L acid in different volume ratios was investigated to determine an improvement in the C-L acid latent heat store. DSC results showed that the combination in equal volume ratio provided the best melting characteristic (164 kJ/kg, latent heat and 8.2°C, melting temperature), presenting an improvement in the C-L acid for low-temperature TES application.

Keywords: low temperature, thermal energy storage, capric-lauric (C-L) acid, phase change material.

Introduction

Fatty acids as phase change materials were cited as promising candidates for energy storage systems in building application. They have the commonly known characteristics of melting congruency, chemical stability, non-toxicity and negative supercooling. More significant of their characteristic is their small volume change during melting and freezing.

The latest research on the mixture of C-L acid was made (Dimaano and Watanabe, 1999; Dimaano and Escoto, 1998). The mixture exhibited a potential as a latent heat store with its heat of fusion value of 148 kJ/kg. Its melting point, however (18°C) is too high to consider it for the cooling purpose of a residential or industrial space unit. In order to maintain a comfortable temperature of 22 to 25°C in a space unit having an ambient temperature range of 30 to 35°C, a temperature below 10°C must be delivered by the storage system, to achieve dehumidification. This requires a maximum melting temperature of about 7 to 10°C for the cold side storage (Thumann, 1991). Seeing the possibility of maintaining a melting point lower than 18°C for the mixture of the C-L acid, this study aims to confirm the storage capability of the C-L acid mixture combined with pentadecane.

Pentadecane offers high latent heat with low melting point. Its melting point (9.9°C) falls within the range suitable for cold storage. However, disadvantage of its use lies on the fact that its price is expensive. With the C-L acid offering similarities with pentadecane in regard to chemical stability, recycleability, and chemical characteristics, the combination of the C-L acid and pentadecane may well serve its purpose of further improving its quality as good phase change material for low temperature TES. The mixture of these 2 kinds of PCMs may mix in the ratio such that their melting point is minimum.

This paper aims at investigating the thermal behavior of the C-L acid with pentadecane for possible low temperature thermal energy storage application.

Experimental Procedure

A. Material

Capric acid, lauric acid and pentadecane are manufactured by Tokyo Chemical Industry, with purity of 98 % for both capric acid and lauric acid, and 99% for pentadecane. The C-L acid is in the ratio of 65 and 35 by mole percent composition of capric acid and lauric acid, respectively. Preparations of PCM mixture are composed of five different combinations of the C-L acid and pentadecane, in terms of their respective proportions of 90:10, 80:20, 70:30, 60:40 and 50:50 % by volume (C-L:Pentadecane mixture). The melting peak and heat of fusion of these five different PCM combinations were determined using the DSC thermal analysis (TA Instruments DSC 2010) method. In order to provide a more distinct limit during the charging process of the PCM, the melting band was defined in terms of the 90% of the total height of the endotherm based on the melting peak. The 90:10 C-L:Pentadecane mixture provided the lowest melting point and heat of fusion value (**Table 1**). Two distinct melting peaks were obtained for the 90:10, 80:20 and 70:30 C-L:Pentadecane.

The peaks widen the melting band at the same time indicating incomplete homogeneity in the mixture during the heating process. Between the 60:40 and 50:50, the latter provided a narrower melting band, although a not so distinct peak, as compared to the other proportions, was also seen. Representative DSC graphs are shown in **Fig. 1**. Three volume proportions (90:10, 70:30, and 50:50) are herein studied to evaluate on which mixture would provide a better thermal behavior for low-temperature thermal energy storage system.

B. Procedure

Figure 2 provides the schematic of the test used in this investigation. A vertical coaxial cylindrical heat exchange storage capsule consists of a copper tube containing the PCM and an acrylic annular cylinder for continuously flowing water during the heating and cooling processes with type K thermocouple probes inserted in its inlet and outlet water provisions. The PCM probe set-up is composed of 10 similar type thermocouples arranged as indicated in **Fig. 3** to determine the radial temperature distribution in the PCM. The height position of the probe set-up varies in each run located 0, 100, 200, and 300 mm from the bottom of the copper cell for the PCM's axial temperature distribution. All these thermocouples are connected to a PC based electronic datalogger. Temperature of the inlet water is controlled with the use of a heater/cooler waterbath during the melting and solidification processes at a flowrate of $1.67 \times 10^{-5} \text{ m}^3/\text{s}$.

Results and Discussion

The typical radial and axial melting and solidification temperature profiles in the PCM were determined. Melting takes place dominantly at about 20°C with a not so constant temperature maintained on the outer radii as shown in **Fig. 4**.

During the solidification process, the solid phase is formed concentrically inward inside the copper tube as seen in **Fig. 5**. The storage of energy in the form of latent heat of fusion progresses within the melting band with solidification taking place at about 20°C. As expected, complete solidification takes more time since the dominating resistance is that of the solid phase with conduction mode of heat transfer controlling.

The charging time for the different PCM combinations exhibited in **Fig. 6** indicates that melting proceeds from top to bottom with the 50:50 CL:Pentadecane mixture providing the least charging time. Except for pentadecane, the melting trend in the order of decreasing melting time of the mixture of C-L acid and pentadecane is logical with the 90:10 ratio having the longest melting time due to its widest melting range and having the highest limit in the melting band temperature. The pure C-L acid, which has a slightly lower temperature with respect to the upper melting band limit compared with the 90:10 mixture, should have melted longer. Likewise with 50:50 mixture which is higher than pure pentadecane. The experimental discrepancy, however, obtained on both cases is acceptable since complications indeed arise due to the combination of conduction and convection heat transfer controlling during the melting process. Moreover, the shorter melting time

accounted for the 50:50 ratio is also due to the alteration in the colligative property of pure pentadecane combined with the mixture of the C-L acid.

The solidification time presented in **Fig. 7**, on the other hand, demonstrates that solidification proceeds from the lowest axial position upward. The solidification trend, based on the lower melting band limit of the CL:pentadecane mixture, is reasonable taken on their order of decreasing solidification time. The 50:50 CL:Pentadecane mixture depicted the least solidification time among the PCM combinations while pure pentadecane exhibited the longest solidification time. Having the lower temperature in the melting band limit of the mixture, the 90:10 ratio, should have obtained the longest solidification time. Its difference incurred, however, with respect to the 70:30 ratio, is acceptable noting the lower temperature limits in their melting bands that presents only a difference of 0.1°C. Similarly, with the pure C-L acid having the highest temperature in the lower melting band limit, it must have incurred the shortest solidification time, followed by pure pentadecane. The behavior of pentadecane against the pure C-L acid exhibits a logical trend due to the higher thermal conductivity of pentadecane over the C-L acid. Thermal conductivity plays a significant role in solidification due to the control of conduction heat transfer.

Furthermore, a non-symmetry in the melting and solidification temperature profiles are also observed in the mixture particularly in the 50:50 mixture. This is explained by the establishment of the mushy zone during melting and solidification (Otooni, 1998; Mc Nulty, J.P., et al., 1994). Similarly, this behavior becomes more defined as the concentration of component pentadecane to the main C-L system is increased. This indicates that the mushy zone in the mixture becomes stronger and denser. This is characterized by inhomogeneities caused by compositional convection in the melt and in the mushy zone during solidification. The erratic change causing the non-symmetry in the profiles also connotes change in the thermophysical properties of the mixture during phase change. The non-linear temperature gradient produced during the melt is supported by greater convection and the persistent temperature gradient during solidification is controlled by conduction.

Reconsidering the fact that the 50:50 CL:Pentadecane has the narrowest melting band among the mixture with a single peak maintained during charging, the performance of the PCM mixture fares off well enough during the entire period of melt. The characteristic behavior demonstrated by the 50:50 mixture generated questions that need to be answered, hence requiring future investigation. An intensive investigation, however, has to be made concerning the solidification of the above mixture to accumulate a better insight about its efficiency for low thermal energy storage application.

Conclusion

The initial assessment of the thermal performance of the C-L acid:pentadecane mixture exposed an interesting phenomenon that defies the standard manner of PCM melting and solidification. This behavior posed on many questions that need to be quantified. Hence, further investigation has to be made. With the mixtures' melting points ranging from 7 to 8.2°C and heat of fusion values of 142 to 164 kJ/kg, the mixture's fast melting and solidification tendencies can make it qualify for low temperature imposing an advantage considered for useful space unit cooling employing thermal energy storage.

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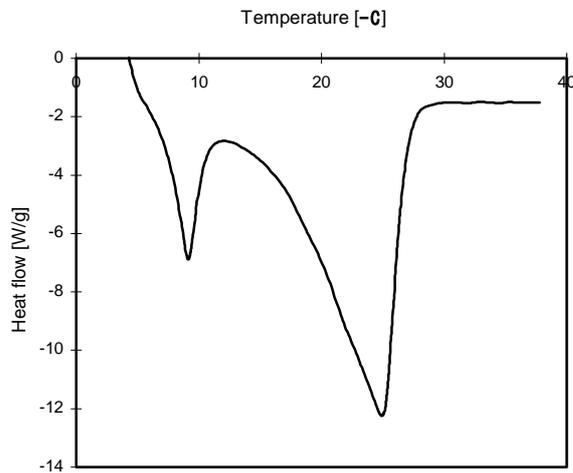
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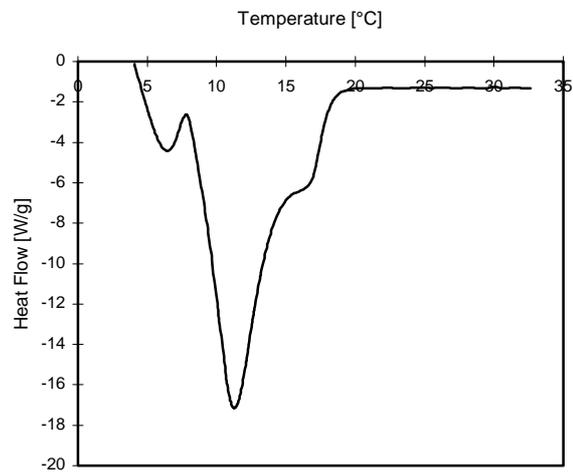
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Table 1. Melting characteristics of the different proportions of the C-L acid and pentadecane mixture.

% by Volume Ratio C-L Acid : Pentadecane	Melting Band [°C]		Melting Peak [°C]		Total Heat of Fusion [kJ/kg]
	Lower Limit	Upper Limit	CL Acid Side	Pentadecane Side	
100:0	17.3	26.0	22.62		148.20
90 : 10	5.2	28.7	24.94	9.12	145.00
80 : 20	5.1	26.0	22.68	9.81	156.50
70 : 30	5.3	23.9	21.01	10.88	158.75
60 : 40	5.6	21.9	6.35	11.28	159.70
50 : 50	7.4	18.4	11.15		164.30
0:100	7.8	15.5		11.50	163.00



(a) 90:10 C-L Acid : Pentadecane.



(b) 50:50 C-L Acid : Pentadecane.

Fig. 1. Representative thermograms of the C-L acid:Pentadecane mixture controlled at a heating rate of 2.5/min.

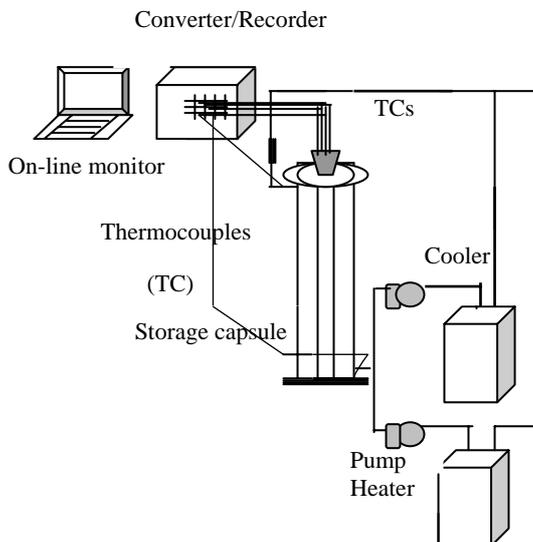


Fig. 2. A schematic diagram of the experimental set-up.

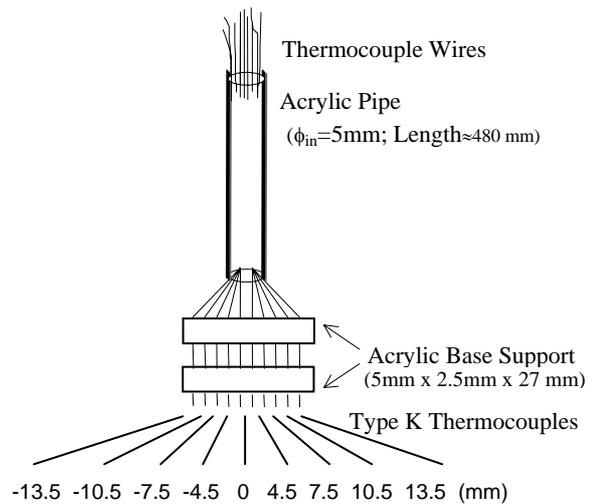


Fig. 3. Chromel-Alumel Thermocouple Probe.

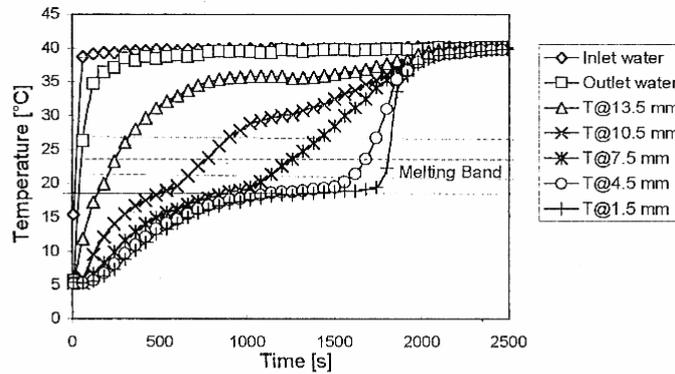


Fig. 4. Pure C-L acid melting temperature history at five different radial positions monitored at 100 mm probe height position.

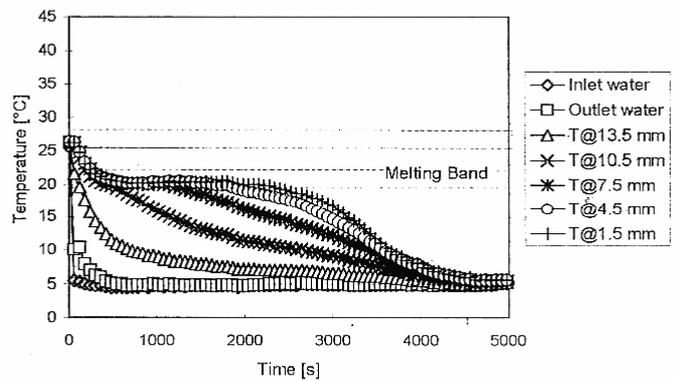


Fig. 5. Pure C-L Acid radial solidification temperature history monitored at 100 mm probe height position.

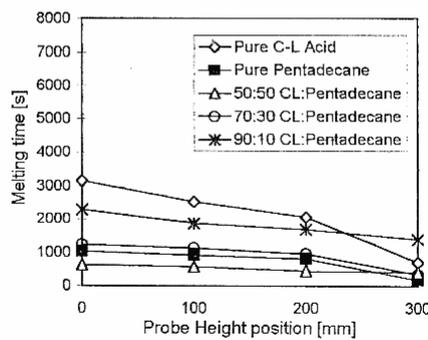


Fig. 6. Axial melting time of the PCMs at 35°C inlet water temperature.

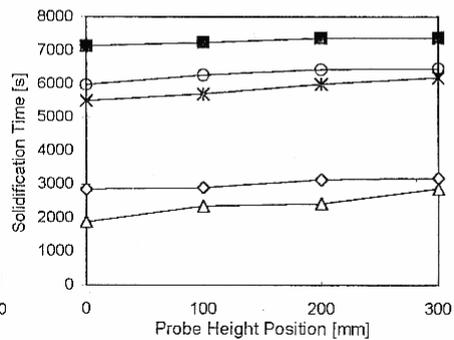


Fig. 7. Axial solidification time of the PCMs at 6°C inlet water temperature.