EXPERIMENTAL INVESTIGATION OF THE APPARENT HEAT CAPACITY OF A PHASE CHANGE EMULSION FOR COOLING APPLICATIONS

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One of the newest two-phase secondary refrigerants studied more and more in the last years are Phase Change Materials Emulsions (PCMEs). PCMEs are latent thermal fluids which consists in small paraffin droplets dispersed in water by the action of a surfactant. Using the strong increase in the apparent heat capacity during phase change of the paraffin droplets from liquid to solid during cooling, the PCME can be used as an efficient cold transport medium. The purpose of the current paper is to investigate the apparent heat capacity of three different versions of 30 wt. % paraffin PCME during cooling in a rectangular plate heat exchanger.

Keywords: phase change emulsion, heat transfer capacity, cooling, refrigeration, thermophysical

1. Introduction

There are more than 20 years now, since a new technique solution was proposed in refrigeration systems, heat exchangers and thermal control systems. Two-phase secondary refrigerants are capable of providing higher energy density than single-phase secondary refrigerants, and hence a substantial reduction in the size of the facility, including the size of pipes. They have high heat transfer rates due to the large surface to volume ratio of the PCM, constant temperature at any point of the cooling distribution network, which guarantees the homogeneity of the temperature, the possibility of implementing thermal energy storage and high rates of transportation. [1-3].

A PCME is a mixture of two immiscible liquids; more precisely, it consists in small droplets of one liquid representing the dispersed phase and a carrier fluid that is the continuous phase [2]. Since the two main components are immiscible, a surfactant is added in order to stabilize the emulsion.

The studied PCMEs are composed out of water, paraffin droplets, surfactant and nucleating agent, as illustrated in Fig. 1.

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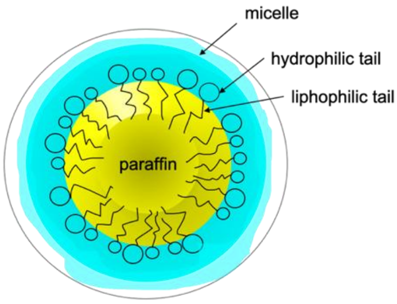

Fig. 1 Illustration of a PCME droplet

In 2018, Vasile *et.al*, investigated the heat transfer behavior of a PCME with 30 wt. % paraffin mass concentration. Results showed that local heat transfer coefficients are higher for a higher Reynolds number. The correlations proposed by the authors for the prediction of the number of Nusselt for this type of flow constitute a first tool for the design of heat exchangers that use PCMEs [4].
PCMEs have been very studied in recent years, the research interest was focused on the preparation methods, reducing the supercooling degree, analyzing their thermal properties and the evaluation of both heat transfer and rheological behavior [4], [8-14]. There is still a lack of information and results for these paraffin emulsions. At present, their utility in practical applications is still questionable.
Therefore, this paper investigates the performance in terms of heat capacity in order to assess the benefits obtainable by using such a fluid as a thermal transporter fluid in practical application.
The authors, Vasile et.al, 2017, 2018 [1,4] did previous studies on the PCMEs, in terms of heat transfer. This paper comes as a continuation of this work presenting a more practical approach for the use of the PCMEs.

2. Analysis of the heat capacity of the PCME

In previous papers, different types of paraffin emulsion were studied by the authors. The results showed that in terms of heat transfer, all types of investigated emulsion showed heat transfer coefficients that are almost or even comparable to those for water under the same working conditions. Despite the fact that PCMEs give birth to higher energy pump consumption by means of high viscosity during and after phase change [5-7], special pumps can be used and the loss can be replaced by the winning from the heat transport capacity, given by the product between the mass flow and specific heat capacity, $\dot{m} \times c_p$. Therefore, the emulsion presents an extra important advantage for practical use, given by the heat transport capacity, which is much higher for PCME, due to the increase in the cp during phase change of the paraffin droplets from liquid to solid. This aspect is thoroughly investigated in this paper, the analysis being done on different types of PCMEs. The studied paraffin emulsions are composed of water, paraffin, nucleant agent and various types of surfactant. The difference between the 3 investigated versions is given by the type of surfactant used in the formulation. Every type of PCME has a different surfactant type and concentration chosen by the industrial manufacturer of the PCME.

3. Application to the experimental data

An experimental test consists of cooling the PCME in a rectangular plate heat exchanger in order to investigate the evolution of different temperatures such as inlet and outlet temperatures of the fluid, inlet and outlet temperatures of the cooling agent, as well as the wall temperatures of the heat exchanger. Different other physical parameters are measured during this experimental test, such as density and mass flow. The entire set of experimental data is used to calculate the apparent heat capacity of the emulsion during cooling in the heat exchanger.

A typical temperature curve of the PCME during cooling in the cooling channel is illustrated in Fig. 2. One can observe a variation of the curve at approximately 1000 s, that may change depending on the tested PCME. This decrease in the slope is designated to the beginning of the paraffin solidification at about 5-6 °C. During phase change, the density, mass flow and heat capacity of the PCME have large variations.

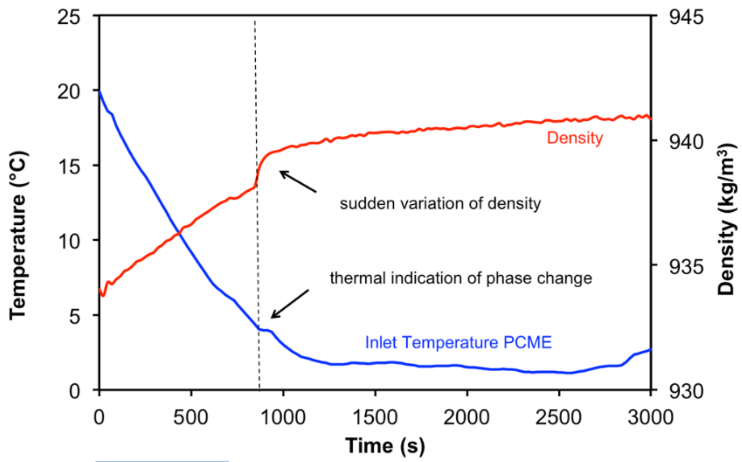

Fig. 2 Thermal indication of phase change during cooling of the PCME in a rectangular plate heat exchanger

In this paper three different types of PCMEs are investigated from the point of view of the apparent heat capacity during cooling. First version of PCME,

PCME V1 is a 30 wt.% paraffin mass concentration with no specifications on the type and concentration of surfactant. The second version of PCME, PCME V2 is a 30 wt. % paraffin mass concentration with 3 wt. % surfactant with the specification that the surfactant is different in comparison with PCME V1.

The third version of PCME, PCME V3 is a 30 wt. % paraffin mass concentration with 3 wt. % surfactant with the specification that the surfactant is the same as for PCME V2. The difference between PCME-V2 and PCME-V3 is given more exactly by the emulsification process and the period of storage before testing, which can change the thermophysical properties of the emulsions.

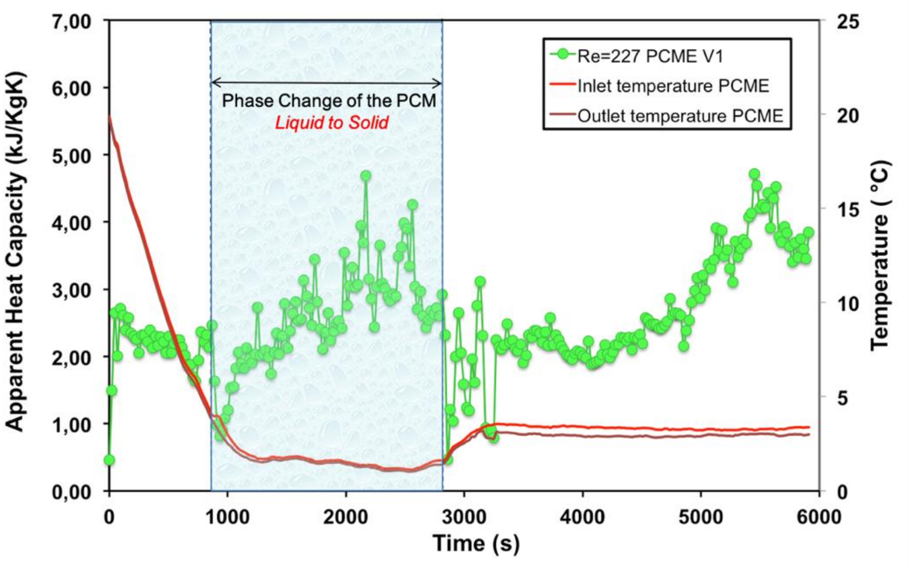

Fig. 3 Apparent Heat Capacity for PCME Version 1 during cooling in a rectangular plate heat exchanger

Analyzing the results on the first version of the emulsion, PCME V1, in terms of the apparent heat capacity, illustrated by the green curve-dots, one can observe that from the start of the phase change, at approximately 1000s, the apparent heat capacity shows an important increase. This investigation was done for a laminar flow, more precisely at a Reynolds equal to 227. Fig. 4, an enlarged picture of both temperature and apparent heat capacity evolution of the PCME V1, shows the moment of the beginning of the transformation of paraffin droplets from liquid to solid, at 890 seconds, together with the sudden increase of the apparent heat capacity. This increase seems to be corresponding to the entire period of the phase change. For 2000 seconds, during the solidification of the paraffin droplets, the emulsion has a capacity up to 2 times greater than usual.

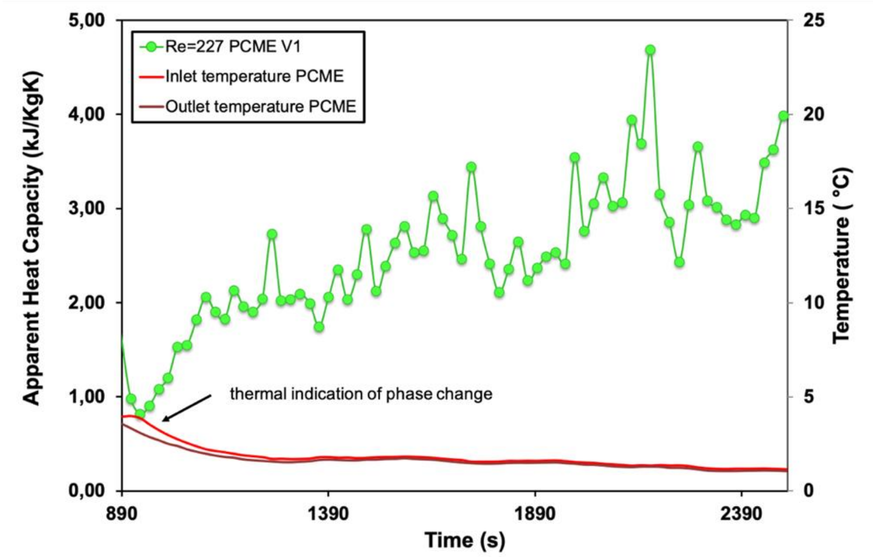

Fig. 4 Zoom on the variation of the temperature and apparent heat capacity during cooling of the PCME V1

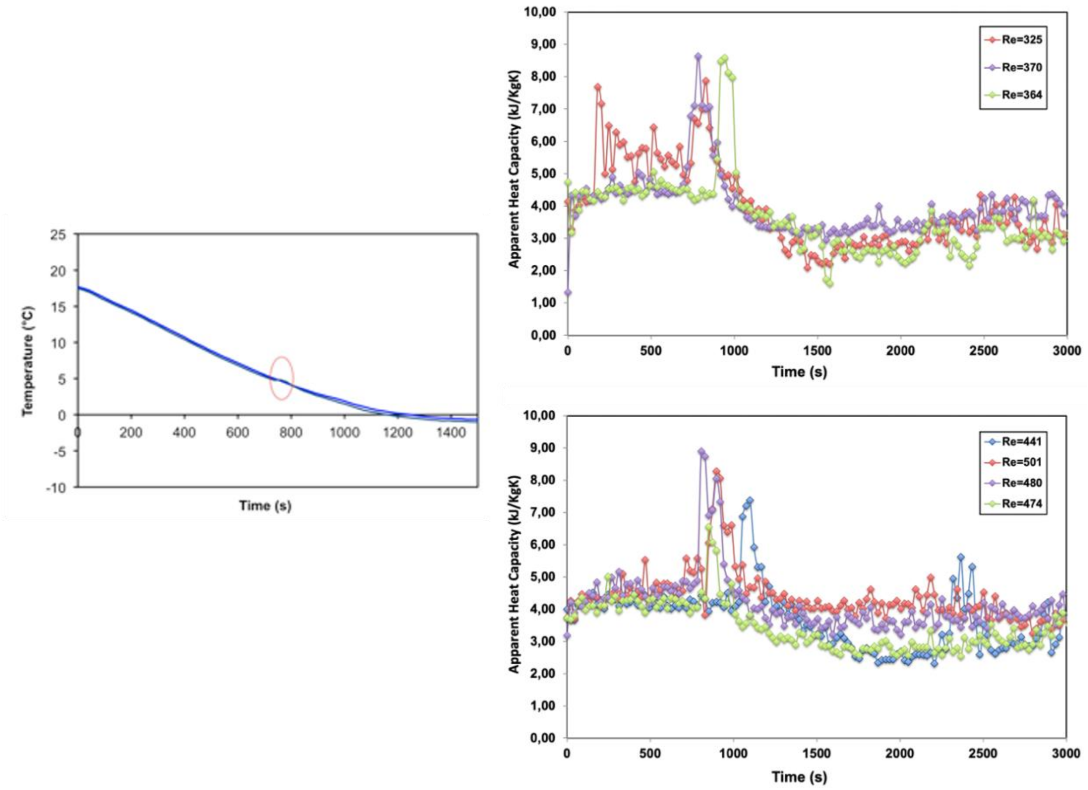

Fig. 5 Results of the apparent heat capacity for the PCME V2 during cooling

Results obtained in terms of PCME V2, show an evolution of the apparent heat capacity comparable to the original version, PCME V1. It can be seen on the figure the concordance between the onset moment the of phase change, noticeable on the evolution of the emulsion's temperatures and the sudden increase in the apparent heat capacity for the exposed working conditions. It can also be observed that by the time of the phase change, at about 800 seconds of cooling and a temperature of approximately 5 °C, the apparent heat capacity has a value two times higher, compared to PCME V1, doubling its value during the phase change. After the phase change, the apparent heat capacity has lower values. Experimental tests were done for various Reynolds number as illustrated in the figure in order to demonstrate the repeatability of the phase change phenomenon, as well as the repeatability of the behavior of the apparent heat capacity at the time of phase change.

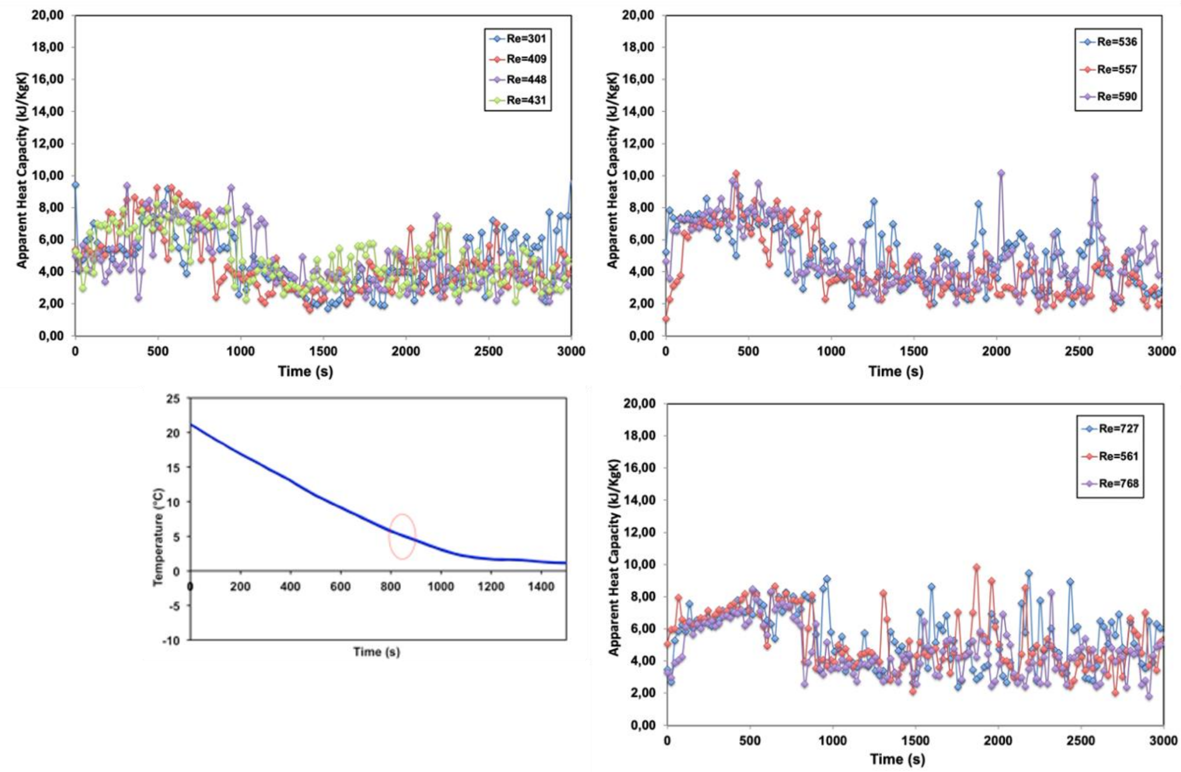

Fig. 6 Results of the apparent heat capacity for the PCME V3 during cooling

One can observe, on Fig. 6 that for the version PCME V3, the evolution of the apparent heat capacity is slightly different from its evolution for the PCME V1 and V2. This difference could be given by the delay in the phase change of the paraffin droplets, due specifically to the supercooling phenomena. The paraffin droplets need more time to crystalize. From the description of the producer, regarding the PCME composition, between PCME V1 and PCME V3, the type of surfactant used gives the difference. In comparison to PCME V2, PCME V3 presents a delay in triggering the phase change, therefore the heat transfer performance is negatively influenced. These differences could be related to storage time before testing and the emulsification process which is unknown to the authors An emulsion that does not change phase or shows a high supercooling degree would not be suitable for industrial applications. For smaller Reynolds number from 200 to 400, PCME V3 has a better heat transfer performance, as previously showed by Vasile *et al.*, 2019 with good heat transport performance, but while for higher Reynolds number, above 400, PCME V1 seems more appropriate with an increased heat transfer performance and similar heat transport rates. As for PCME V2, experimental tests were done for various Reynolds number to demonstrate the repeatability of the phase change phenomenon, as well as the behavior of the apparent heat capacity at the time of phase change

5. Conclusions

When using a PCME as coolant for industrial applications, different key factors are identified as being necessarily studied. From an application point of view, the increased heat transport capacity of the PCME together with the heat transfer coefficients are very attractive but the increased viscosity tends to affect this benefit by generation of higher energy pump consumptions. It is advisable to maximize the use of the latent heat capacity of the PCME. Increasing the heat transport capacity can reduce the flow rates of the fluid used, which means smaller circulation pumps and lower energy consumption, thus the interest of this paper in the analysis of the apparent heat capacity of the PCME.

This paper presents the results obtained on the apparent heat capacity of three different versions of 30 wt. % paraffin PCME during cooling in a rectangular plate heat exchanger. Results showed an interesting but expected behavior regarding this parameter, namely a sudden increase in the values of the apparent heat capacity corresponding to the phase change of the paraffin droplets from liquid to solid.

All three versions of PCME show more or less important increases, in terms of the apparent heat capacity during the phase change, depending on the composition of the emulsion. Of all, the second version of the emulsion, the PCME V2 is particularly notable. This one shows a greater increase during the phase change, which is consistent with the authors' previous results. The PCME V2 has the lowest supercooling degree, good heat transfer coefficients and greater stability at the time of phase change. In addition to all this aspect, the string increase in the apparent heat capacity during phase change of droplets from liquid to solid during cooling show that the PCME can be used as an efficient cold transport medium.

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