Preliminary thermal characterisation of an active latent thermal energy storage system using PCM

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Abstract. Preliminary results of energy charging/discharging processes in a latent thermal energy storage system are reported. A novel design of a rotative scrapper heat exchanger has been studied. Paraffin RT44HC is employed as a phase change material. A Coriolis flowmeter is employed for measuring the mass flow through the prototype, and PT100 temperature sensors are used for measuring the inlet and exit temperature of the heat transfer fluid.

1. Introduction

The intermittency of solar energy has made necessary the development of thermal energy storage technologies (Thermal Energy Storage, TES). The storage of latent heat (Latent Heat Storage, LHS) allows to increase the thermal energy accumulated by the material of phase change (Phase Change Materials, PCM), with a much lower temperature change in contrast with sensible heat systems. In the LHS method, energy is stored by changing a material’s phase at a relatively constant temperature. The use of PCM materials for LHS purposes, however, presents major drawbacks that must be addressed, such as long-term stability of storage properties, low thermal conductivity, phase segregation and subcooling during the process phase change.(1)(2)

Some studies have evaluated different accumulators based on shell-and-tube technologies. Agyenim et al. (3) demonstrated the superior performance of tubes with longitudinal fins, compared to circular finned-tubes and smooth tubes. The importance of natural convection in the melting process of the PCM has also been studied (4).

Furthermore, some works have studied the heat releasing using active methods. Maruoka et al. (5) tested a rotative heat exchanger and demonstrated the relation between rotation velocity and heat release. Tombrick et al (6) studied a factible solution to solve the problems during solidification due to the formation of a solid layer in the heat transfer surface. This work reports the design and experimental characterization for a rotative scrapper heat exchanger using paraffin with melting temperature of 44 °C, for latent thermal energy storage purposes.

2. Materials and methods

An experimental facility is being built in the research building ELDI at Universidad Politécnica de Cartagena (37.6051° N 0.9862° W in Cartagena, Spain). A sketch of the experimental facility is shown in Figure 1.
Figure 1. Experimental setup. (1) Chiller; (2) Heat transfer fluid tank; (3) Pump; (4) Coriolis Flowmeter; (5) Inmersed PT100 sensors; (6) Rotative LHT storage system; (7) Electric heater.

A circulating pump drives the heat transfer fluid (HTF) from the tank to the Rotative LHT storage system. The temperature of the HTF inside the tank is controlled by a chiller. The HTF used is water. The rotative scraper heat exchanger has been built to store energy using a PCM. Paraffin RT44HC, with a melting area of 40°C - 44°C is employed as PCM. The PCM container is surrounded by a water jacket for heat transfer purposes. In Figure 2 the basic concept of the rotative heat exchanger is shown.

Figure 2. Basic concept of section of the rotative heat exchanger

The fluid throw the water jacket extracts thermal energy from the surface of the heat transfer wall. Simultaneously, liquid PCM releases its phase change enthalpy during solidification at the inner surface of the wall. The rotative scrapers removes the solidified PCM layer. An electric motor is used to control the velocity of the scrapers.

Moreover, for heating purposes, three electric heaters are located in the bottom of the LHT system in order to get the test temperature with high accuracy. Furthermore, PT100 sensors are installed HTF ports to evaluate the heat transfer in the working prototype during melting and solidification process. In addition, T-type thermocouples are included in the LHT system to study the temperature distribution along the LHT system. On the other hand, the mass flow through the facility is measured by a Coriolis flowmeter.
3. Results
In this section preliminary results of heat release and temperature distribution along the scraper prototype are shown. The test was performed preheating the PCM to 60 °C. The flow rate was fixed to 375 kg/h and the prototype inlet temperature to 20 °C. In addition, the scraping velocity during the test was 5 rpm.

The heat release to the heat transfer fluid is computed as:

$$\dot{Q} = \dot{m} \ c_p \ (T_{in} - T_{out})$$

Where inlet temperature \(T_{in}\) and outlet temperature \(T_{out}\) are measured by the PT100 sensors at the top and the bottom of the LHT system, and the mass flow \(\dot{m}\) by the Coriolis flowmeter. In Figure 3 the evolution of the heat release is shown.

![Figure 3. Heat release during solidification.](image)

The evolution of the heat release along time shows three trends. At the beginning of the test, a sharp decrease is observed due to the extraction of sensible heat from liquid PCM. When PCM reaches the solidification temperature, heat release remains around 5 kW. This fact is due to the scraping of heat transfer wall which removes the solid PCM layer. The removing of the solid PCM layer is shown in Figure 4. Once the PCM has been solidified, heat release decreases slowly extracting energy from solid PCM.
During solidification the system is capable of extracting 10 MJ (90 % of the total capacity) calculated with the following equation:

\[ E = \int_{t_1}^{t_2} \dot{Q} \, dt \]  

(2)

In Figure 5 the evolution of the PCM wall temperature measured in the heat transfer wall is presented. The general behaviour of PCM has been explained previously, PCM reaches solidification temperature quickly and remains constant during the solidification process. When solidification ends temperatures decreases.

Moreover, there are some differences in the wall temperature depending on the position of the sensor. During solidification, the solid PCM removed from the surface goes to the bottom by gravity forces. As a result, at the top of the system the PCM remains liquid more time.
4. Conclusions
In this work a preliminary thermal characterisation of an active LTES system has been carried out. Results of heat release and temperature distribution have been presented.

The preliminary results show the scraping of the heat transfer wall removes the solid PCM layer. Removing solid PCM has been shown as a very promising method to increase the efficiency in LTES systems allowing to extract 90% of phase change energy.

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