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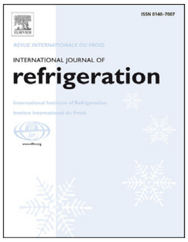

Reproducibility of solidification and melting processes in a latent heat thermal storage tank

F. Bosholm, A. López-Navarro, M. Gamarra, J.M. Corberán, J. Payá *

Instituto de Ingeniería Energética IIE, Universitat Politècnica de València, Camino de Vera s/n, Edificio 8E cubo F
5a planta, 46022 Valencia, Spain

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ABSTRACT

This study analyzes the reproducibility of solidification and melting tests in a tank containing 181 kg of paraffin for cold storage at around 8 °C. Firstly, an experimental campaign of 10 identical tests was carried out. The performance is practically the same in terms of PCM temperatures and thermal power, with a maximum deviation of 2% in the capacity of all tests. In a second campaign, the impact of the initial conditions was studied. The results indicate that fixing a same mean PCM temperature at the beginning of the tests is insufficient to ensure an accurate reproducibility. Depending on the heat transfer rate during the preparation tests, the capacity differed in up to 33%. In tanks with such quantities of PCM, fixing a uniform initial PCM temperature is hardly possible, thus it is important to prepare the tank with same operation conditions.

Reproductibilité des processus de solidification et de fusion dans un réservoir d'accumulation thermique de chaleur latente

Mots clés : Réservoir d'accumulation d'énergie thermique ; MCP ; Paraffine ; Expérimentation ; Reproductibilité

1. Introduction

The research in latent heat thermal storage systems has been very active in recent years, from the synthesis and characterization of phase-change materials (PCMs) to a full system level. This increasing activity can be understood from an energy and economical context (Azeldin El-Sawi et al., 2014; Saman, 2013; Yun and Steemers, 2011) such as the climate change, the rising energy prices and the higher penetration of renewables in the energy mix.

Residential and commercial buildings present a high contribution to the worldwide energy consumption among other reasons for air-conditioning (Chua et al., 2013). The peak

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* *Corresponding author.* Instituto de Ingeniería Energética IIE, Universitat Politècnica de València, Camino de Vera s/n, Edificio 8E cubo F 5a planta, 46022 Valencia, Spain. Tel.: +34 963879910; Fax: +34 963877272.

E-mail address: jorpaher@iie.upv.es (J. Payá).

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Nomenclature

$\dot{m}$	mass flow rate [kg s^{-1}]
C_p	specific heat [J kg^{-1} K^{-1}]
E	energy [J]
T	temperature [°C]
$\dot{Q}$	thermal power [W]
t	time [s]

Abbreviations/subscripts

TES	thermal energy storage
PCM	phase change material
supply	inlet temperature of the tank
HTF	heat transfer fluid
RST	reproducible solidification test
RMT	reproducible melting test
LHS	latent heat storage
SHS	sensible heat storage
return	return temperature of the tank
init	initial conditions
NRST	non reproducible solidification test
NRMT	non reproducible melting test

demand of electricity is actually growing faster than the total use of electricity (Newsham and Bowker, 2010), and in many countries the prices in on-peak and off-peak periods are significantly different. In this context, cold storage is an interesting solution given that it is considered to be cheaper than electricity storage (MacCracken, 2010).

PCMs have been used for decades for load shifting (Brousseau and Lacroix, 1996; Saito, 2002). Available cold storage technologies have been reviewed (Oró et al., 2012), addressing both sensible and latent heat storage. Water as PCM is cheap and has very good thermo-physical properties even on a long term. Another option is using ice-slurries, which have been studied for different applications (Kauffeld et al., 2005, 2010, Shao et al., 2015).

The use of ice storage with respect to other PCMs is a compromise between the investment cost of the tank and the energy efficiency of the installation. The energy efficiency in HVAC systems is particularly hindered because of the low temperatures required for the solidification (Beghi et al., 2014; Rismanchi et al., 2012; Sehar et al., 2012). PCMs with higher melting temperatures than ice/water can increase the energy savings, for example Bruno et al. obtained savings of around 13.5% with a melting temperature in the PCM of 10 °C (Bruno et al., 2014). Given that the chilled water temperature of a conventional air-conditioning system is typically supplied at 7 °C, there is a significant interest in PCMs with a phase-change temperature in the range of 5–10 °C (Farid et al., 2004).

Paraffins are an interesting option for cold storage given their commercial availability, relatively high melting enthalpy and a good cyclic behavior. Recent advances aim to enhance the thermal conductivity, to increase the phase-change enthalpy or to obtain cheaper PCMs (Peñalosa et al., 2014).

On a practical basis, literature on tanks with a significant capacity remains relatively scarce (Banaszek et al., 1999; Gil et al., 2014; Tay et al., 2012). Most of this published work involves a characterization of the tank performance depending on the operation conditions (e.g. mass flow rates, supply temperatures) but the initial conditions are generally presented very briefly, and they usually consist in fixing a same mean PCM temperature in the tank.

Paraffins are known to have a stable cyclic behavior in specific setups with small samples. However, in tanks with a significant PCM capacity, the determination of a unique initial state is not straightforward due to the low thermal conductivity, to the buoyancy effect and to the long periods which are necessary to ensure a full solidification or melting in PCM. Therefore, the scientific question which arises is if the tank performance is reproducible, rather than if the PCM is thermodynamically stable after many cycles.

This work has a direct link with practical cold storage installations, where the operation strategies have to be designed to ensure a correct performance of the tank. A simple solution can be to determine the state of the tank using PCM temperature sensors. However, the present study indicates that the heat transfer rate at which the charging is done has a significant impact on the thermal storage performance.

To the authors' knowledge, on a tank level, no studies have been carried out to demonstrate if the tests are perfectly reproducible when executed under identical operation conditions, and to quantify the impact of the initial state on the tank's thermal energy storage. The present results indicate that having a same mean PCM temperature in the beginning of the tests is insufficient to ensure a perfect reproducibility, particularly in tanks with dead volumes where small temperature fluctuations around the phase-change temperature can have a significant impact in the measured thermal energy storage capacity.

2. Material and methods

2.1. Experimental set-up

The LHS tank was built and tested at the Polytechnic University of Valencia. In a recent publication (López-Navarro et al., 2014) the experimental set-up, the instrumentation and the experimental uncertainties were described in detail. Thus, the present section focuses on providing the basic data of the tank and in describing the test procedure.

As indicated in Fig. 1, the tank has an internal heat exchanger which consists of 8 spiral-shaped coils placed in counter flow. The 8 coils are connected with 4 vertical collectors, two in the center and two in the external part of the tank. In total, the heat exchanger has a surface of 5.75 m^2 in contact with the PCM. This coil design presents the disadvantage of having a low heat transfer surface in contact with the PCM but it helps to reach a significant storage capacity with a relatively cheap heat exchanger, already available for instance in ice-storage solutions. Filling the tank with a hydrated salt would theoretically lead to a higher capacity, although on a long term the PCM stability or corrosion problems could appear.

The tank contains 181 kg of the paraffin RT8 (Rubitherm GmbH, 2014). According to T-history measurements, the phase-change mainly takes place in the temperature range from 3 to 8 °C The total enthalpy variation from 0 to 15 °C is 176 kJ kg^{-1} (Rubitherm GmbH, 2014). This provides a maximum theoretical capacity of 31.8 MJ.