Applied Thermal Engineering 99 (2016) 880–891

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Experimental assessment of a phase change material storage tank

Katherine D'Avignon *, Michaël Kummert

Department of Mechanical Engineering, Polytechnique Montreal, Montreal, Quebec, Canada

HIGHLIGHTS

- A storage tank with PCM capsules was tested experimentally.
- The complete data set from all tests (3 repetitions/test) is made available.
- State of charge cannot be determined from outlet temperature.
- Interrupting cooling or heating alters phase change temperature.
- PCM behaviour varies but tank behaviour can be predicted from operating conditions.

ARTICLE INFO

Article history:
Received 7 September 2015
Accepted 13 January 2016
Available online 1 February 2016

Keywords:
Phase change material storage tank
Experimental testing
Interrupted phase change

ABSTRACT

This paper describes the experimental study carried out to assess the performance of a Phase Change Material (PCM) storage tank in various operating conditions in a dynamic test bench. The studied horizontal PCM tank contains stacks of slab-like PCM capsules between which heat transfer fluid can circulate. The commercially available capsules were instrumented so the PCM behaviour could be measured in addition to that of the PCM tank as a whole. Numerous melting and solidification cycles were completed with different inlet fluid temperatures, flowrates and load profiles for which at least three repetitions were made. Analysis of test results shows significant variations in the PCM behaviour under the same tests conditions including varying degree of supercooling and differing phase change temperature. The outlet fluid temperature from the tank can however be predicted accurately from operating conditions and the initial state of the PCM. Interrupting phase change processes before the PCM is completely melted or solidified affects the temperature at which the PCM changes phase as well as the degree of supercooling measured. Results from this investigation will be especially useful for researchers developing and validating numerical models for use in various building energy systems as the complete experimental data set is made available as an online companion to this paper.

1. Introduction

Design, automated control and fault diagnostics in building energy systems increasingly rely on modelling and performance simulation of Heating, Ventilation and Air-Conditioning (HVAC) equipment. As HVAC equipment is significantly influenced by its surroundings and the operating conditions it experiences, data encompassing the whole operating range of each component are required for proper simulation. Unfortunately, standardised data provided by manufacturers are often limited to a few number of operating points.

Heat pumps are a good example of HVAC components that present a performance that is highly dependent on the variation of its operating conditions. Novel components such as phase change material (PCM) storage tanks are another example where the nominal capacity is insufficient for designers to assess their correct dynamic operation. As shown by Liu et al. [1,2], something as critical as the rate at which heat can be stored or extracted can vary significantly with operating conditions.

Moreno et al. [3] experimentally compared the performance of a water storage tank to that of a PCM storage tank to shift the daytime cooling load of a small space when coupled to a water-to-water heat pump and air handling unit. Both thermal energy storage (TES) tanks were horizontal and had identical dimensions but the PCM tank included stacks of a commercially-available PCM supplied in plastic rectangular capsules. Results indicate that for the same footprint, the PCM tank could on average supply 14.5% more cooling energy than the water tank, at the expense of a charging time which was 4.6 times longer. Results such as these are promising but thorough testing of such PCM capsules and tank configuration are required for HVAC system designers to consider installing them in their projects.

Thorough model validation of PCM storage tanks also requires testing multiple operating conditions for a specific PCM tank configuration so that the model can truly be validated for use in

* Corresponding author. Tel.: +1 514 340 4711 #5896; fax: +1 514 340 5170.
E-mail address: katherine.davignon@polymtl.ca (K. D'Avignon).

http://dx.doi.org/10.1016/j.applthermaleng.2016.01.083
1359-4311/

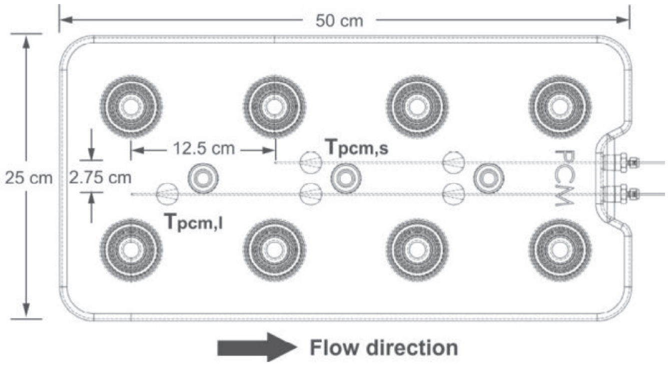

Fig. 1. Instrumented PCM capsule.

various applications. Dutil et al. [4] indicate that most recent studies have relied on numerical results from previous researchers to validate their models and that experimental data are scarce for most recent geometries. Dolado et al. [5] performed such thorough testing of a PCM-air heat exchanger which included metal-encapsulated PCM slabs positioned vertically. The impact of varying the fluid flowrate and inlet fluid temperature on the thermal power produced by the unit was evaluated. Detailed figures provide the time evolution of the temperature measured at the surface of all the PCM capsules inside the unit as well as the fluid inlet and outlet temperatures. Other such tests exist for PCMs encapsulated in plastic pouches [6,7], in plastic vertical slabs [8,9], as well as spherical [10–12] and cylindrical capsules [13]. Such thorough analysis of thermal energy system behaviour has not been done for the commercially available capsule type described in Moreno et al.'s work.

This paper describes the experimental tests carried out to evaluate the behaviour of a real-scale PCM storage tank in varying operating conditions. For this purpose, the Semi-Virtual Lab at Polytechnique Montreal was adapted to the study of single inlet/outlet storage tanks where small flowrates were required. A horizontal tank was designed to contain stacks of commercially available slab-like PCM capsules between which heat transfer fluid could circulate. The capsules containing the PCM, a salt hydrate, were instrumented to allow measurement of the material behaviour in addition to that of the PCM tank as a whole. Numerous melting and solidification cycles were completed with different inlet fluid temperatures, flowrates and load profiles for which the results are presented here. Detailed analysis of test results allows to draw conclusions regarding the phase-change material itself, the PCM capsule and overall tank behaviour. The complete experimental data set is made available to readers as an online companion to this paper in order to assist in the development and validation of PCM tank models.

2. Experimental set-up

As illustrated in Fig. 1, the commercially available PCM objects tested in this project are rectangular HDPE capsules which are 0.25 m wide, 0.5 m long and 0.032 m thick. Two rows of protrusions are present on their upper and lower faces which interlock when stacked to hold the capsules at a distance of 0.007 m away from one another (see Figs. 2 and 3).

A series of holes along the central axis of the capsule penetrate to the capsule centre and one lateral face includes a depression where the sealed filling orifice is located. In this study, the PCM contained in the capsules is a heterogeneous salt hydrate named S27 [14] whose properties as supplied by the manufacturer are detailed in Table 1.

Table 1
PCM properties of S27 as specified by the manufacturer.

Phase change temperature	27 °C
Density	1530 kg/m^3
Latent heat of fusion	183 kJ/kg
Volumetric heat capacity	280 MJ/m^3
Specific heat capacity	2.20 kJ/kg-K
Thermal conductivity	0.540 W/m-K
Mass	5.81 kg/capsule

As can be seen in Fig. 2, PCM capsules were installed inside a horizontal insulated cylindrical tank in a 2 stacks wide by 2 stacks deep formation, for a total of 32 capsules. The PCM tank is equipped with perforated plates at its inlet and outlet to allow uniform fluid flow across the capsule faces. This results in an entry/exit volume of 81 L, located between the fluid entry/exit and the perforated plate, which is filled with fluid and exempt of any PCM capsules. The zone located between the two perforated plates has a diameter of 0.762 m and length of 1.05 m and is where the capsules were installed. A section made of expanded polystyrene was used to support the capsules inside the tank and insulate them from ambient conditions. This support section held the capsules in an opening 0.5 m wide and 0.37 m in height. An additional layer of insulation (in light purple on Figs. 2 and 3), 0.013 m in height, was added to fill the gap between the capsule stack and the capsule support. One of these commercially-available PCM capsules is instrumented by the researchers with two Type-K thermocouples, installed at two positions along the capsule's length, near its central axis (see Fig. 1). As shown in Fig. 3, the instrumented capsule is installed in the "downstream" stack of capsules (second row in direction of flow) about

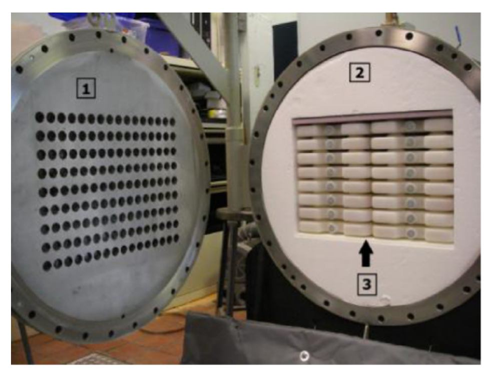

Fig. 2. PCM tank viewed from the inlet, including (1) perforated plate, (2) capsule support and (3) PCM capsules.

Fig. 3. Position of the instrumented PCM capsule in the tank as viewed from the outlet.