Applied Energy 109 (2013) 433–440

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Improved measurement technique for the characterization of organic and inorganic phase change materials using the T-history method

Stanislava B. Stanković *, Panayiotis A. Kyriacou

School of Engineering and Mathematical Sciences, City University London, Northampton Square, London EC1V 0HB, UK

HIGHLIGHTS

- ▶ We implemented the precise T-history control and sensing setup.
- ▶ Data processing algorithm was adjusted to take the effect of subcooling into account.
- ▶ T-history measurements of organic and inorganic PCM samples were performed.
- ▶ High temperature accuracy in PCM measurements was achieved.
- ▶ Reduction of heat release/storage uncertainties between cooling and heating cycles was achieved.

ARTICLE INFO

Article history:
Received 1 August 2012
Received in revised form 29 December 2012
Accepted 27 January 2013
Available online 21 February 2013

Keywords:
PCM
Characterization methodology
T-history method
Subcooling
Temperature uncertainty
Heat density

ABSTRACT

In the past decade, the interest in phase change materials (PCMs) has grown significantly due to their ability to store large amounts of thermal energy in relatively small temperature intervals. Accurate knowledge of thermo-physical properties is a prerequisite for any reliable utilization of these materials. The T-history method is widely used for the investigation of PCM. This paper presents an improved measurement technique for the characterization of PCM using the T-history method. The suggested improvements include the arrangements made in three different prospects: the experimental setup, data processing and data representation. T-history measurements of organic RT21 and inorganic SP22 A17 (RUBITHERM® GmbH) PCM were performed. The applied arrangements resulted in the temperature accuracy of ±0.3 °C and the reduction of uncertainty associated with heat stored/released between the cooling and heating measurements. The obtained results showed some important aspects of the T-history PCM investigation and could provide more effective design and development process of the thermal energy storage systems based on the investigated materials.

1. Introduction

In the past decade, the interest in phase change materials (PCMs) has grown significantly amongst researchers as indicated in the most recent review papers by Oró et al. [1] and Zhou et al. [2] as well as in an earlier one by Zalba et al. [3]. Namely, these materials, due to their ability to store large amounts of thermal energy in relatively small temperature intervals, can be effectively used for various thermal energy storage (TES) applications [4]. Nevertheless, according to Mehling and Cabeza [4], one of the limiting factors for the effective application of PCM is the lack of the experimentally determined material data. Accurate knowledge of thermo-physical properties is a prerequisite before the design process and the real time deployment of any TES application based on PCM or PCM slurries as indicated by Diaconu et al. [5] and Lu and Tassou [6].

The T-history method, introduced by Yinping et al. [7], is widely used for the investigation of phase change materials. The majority of the T-history studies reported in the literature during the last 20 years aimed to reduce the temperature and the heat storage uncertainty associated with the PCM measurement. Accordingly, Marin et al. [8] improved the mathematical evaluation model developed by Yinping et al. [7] by using the concept of enthalpy and its relation with the temperature. Furthermore, Lazaro et al. [9] developed a verification methodology for the T-history setup. The most recent T-history procedures include improvements in measurement arrangement and in the way of measurement processing as reported by Kravvaritis et al. [10,11] for the “thermal delay method” and by Moreno-Alvarez at al. [12] for the “dT-history method”. Peck et al. [13] introduced the utilization of the PCM T-history curve’s inflection point as the end of the phase change period instead of the release point of subcooling as suggested in the

* Corresponding author. Tel.: +44 (0)20 7040 3878; fax: +44 (0)20 7040 8568.
E-mail address: stankovic.stanislava.1@city.ac.uk (S.B. Stanković).

0306-2619/$ - see front matter
http://dx.doi.org/10.1016/j.apenergy.2013.01.079

definition of the original method [7]. They also suggested the horizontal placement of the test tubes to avoid natural convection. Reduction of the temperature and the heat storage uncertainties is very important for optimal utilization of PCM since the typical temperature ranges of PCM applications are in the order of ±10 °C around the phase change temperature [14].

This paper presents an improved measurement technique for the characterization of PCM using the T-history method. The main modifications involved in the measurement process are summarized below. Primarily, the suggested improvements include the selection of the thermally controlled environment and the temperature sensing modalities for the T-history setup. This was followed by the development of the adequate instrumentation and data acquisition system. In addition, the mathematical model given by Marin et al. [8] and elaborated by Kravvaritis et al. [10], based on the time delay between the T-history curves at any specified temperature, was adjusted for the data analysis in order to take the subcooling phenomenon into the account. The suggestions given by Sandnes and Rekstad [15] regarding the subcooling were also taken into consideration. The calculated results on heat capacity were presented as heat stored/released in given temperature intervals, as suggested by Mehling et al. [16]. Moreover, the total heat released/stored (between 15 °C and 30 °C) for organic as well as for inorganic PCM in case of both cooling and heating cycles were determined and compared.

2. Materials and methods

The application of the T-history method, as proposed by Yinping et al. [7], requires at least two test tubes, one filled with the investigated PCM material and the other one filled with the reference material. Reference material needs to have very well-known thermal properties especially in terms of the sensible and the latent heat capacity. Distilled water is usually used for this purpose. Test tubes need to be long and narrow in order to keep the Biot's number below 0.1 and ensure the application of the lumped capacitance model [7]. The samples within the tubes are firstly heated to the temperature above the PCM melting point. When the uniform temperature of both samples is achieved they are exposed to the environmental temperature below the melting point. Their temperature history has to be recorded throughout the whole process so the measurement results can be used to evaluate the thermal properties of the PCM [7]. As indicated in the Section 1, important contribution of this study is the development of the precise T-history setup. The main experimental setup and method improvements are summarized below.

A BINDER KMF 115 (BINDER GmbH [17]) environmental chamber was used as the temperature controlled facility. Majority of the reported studies [7–15] do not discuss the details of the experimental setup in terms of the temperature controlled environment. The temperature controlled facilities within the reported experiments are custom built in such way that clear understanding of temperature control implementation is not present. For this reason, we decided to use a high performance commercial BINDER KMF 115 chamber with the guaranteed and precise temperature control. The manufacturer does not reveal the details regarding the temperature control mechanism of the chamber. However, highly precise control from −10 to 100 °C with the temperature accuracy of ±0.2 °C within the chamber is guaranteed by the manufacturer. Guaranteed temperature accuracy is one of the main reasons the BINDER KMF 115 was selected as the temperature controlled environment for the T-history experiments. The chamber was also used for the sensor calibration so relatively high sensor accuracy was obtained. The exterior dimensions of the chamber are: width 88.5 cm, height 105 cm, and depth 73 cm plus the interior dimensions: width 60 cm, height 48.3 cm, and depth 35.1 cm (see Fig. 1). The chamber's temperature controlled range between −10 °C and 100 °C was found acceptable for the investigation of the selected organic paraffin RT21 and inorganic salt hydrate SP22 A17 (RUBITHERM® GmbH [18]) PCM samples. According to the manufacturer's specification RT21 has the melting area between 18 °C and 23 °C and the congealing area between 19 °C and 22 °C with the typical phase change temperature of 21 °C. The heat stored between 15 °C and 30 °C of this PCM is 134 kJ/kg. The melting area of the inorganic PCM SP22 is between 22 °C and 24 °C (typical being 23 °C) and the congealing area is between 19 °C and 21 °C (typical being 20 °C). The heat stored between 15 °C and 30 °C of the SP22 is 150 kJ/kg. Distilled water was used as the reference material in case of both PCM samples since its thermal properties, mainly in terms of the specific heat capacity, are well-known.

One of the aims of this experiment was to characterize relatively large PCM specimens (with the specimen's mass larger than 20 g) so the results could be compared, in terms of PCM thermal characteristics, with the results obtained with smaller masses from experiments reported in literature [19,20]. Therefore, the test tubes were designed and custom built with the aim to have the tubes of maximum possible volume to ensure that the mass of the specimen is above 20 g. The wall thickness of the test tubes was limited to 1 mm since the manufacturer (Dixon Glass Limited [21]) could not make thinner tubes. The height of the test tubes was also limited by the internal height of the chamber to below 48.3 cm. The tubes were made of SIMAX glass with the thermal conductivity of 1.2 W/mK. Given the aforementioned parameters the height and the internal diameter of the test tubes was determined so the Biot's number would be below 0.1 to justify the application of the lumped capacitance model [7]. This way the tubes' height and internal diameter were designed to be 43 cm and 1.3 cm. In all experiments, both the RT21 and the SP22 were put in the test tubes of the same dimensions so the shared parameter for organic and inorganic specimens was volume. Since SP22 (density of 1.49 kg/l in solid and 1.43 kg/l in liquid form) is more dense than RT21 (density of 0.8 kg/l in solid and 0.77 kg/l in liquid form) this resulted in the respective masses of 73 g for SP22 and 41 g for RT21. Both masses were measured when samples were in liquid states.

Continuous temperatures of the samples and the environment temperature were measured using thermistors (Newark MA100G-G103A model [22]). In comparison to other conventional temperature sensors, thermistors were selected for this study due to their high sensitivity [23]. This property makes them particularly

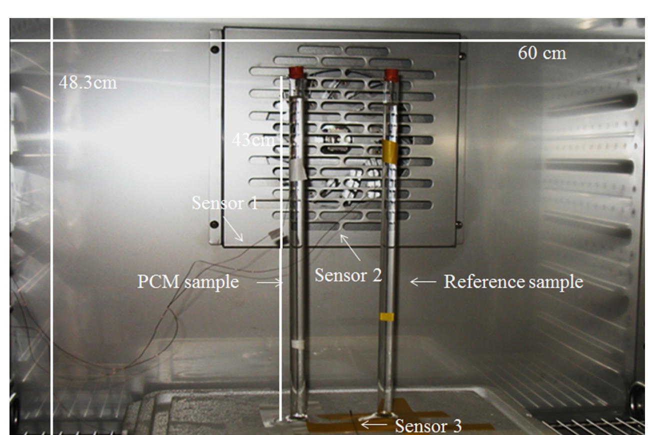

Fig. 1. T-history experimental setup inside the BINDER KMF 115 environmental chamber.