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Paul Byrne, Titin Trisnadewi, Ardiyansyah Yatim, Thierry Maré, Nandy Putra. Experimental Study Based On Thermal Cycles On A PCM Sample For Cold Storage In An AC System. International Symposium on Advances and Innovation in Mechanical Engineering, Oct 2022, Makassar, Indonesia. hal-03921630

HAL Id: hal-03921630

<https://hal.science/hal-03921630>

Submitted on 4 Jan 2023

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Experimental Study Based On Thermal Cycles On A PCM Sample For Cold Storage In An AC System

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Abstract. Air conditioning (AC) systems consume around 60 % of electric energy in hotels in tropical regions. The proposed system uses solar photovoltaic (PV) panels to supply electricity to chiller during the day. The main part of the cooling energy is delivered to the building and the rest is stored in a PCM tank. This energy storage is used for cold restitution during the night. The PCM material is a eutectic mixture of two fatty acids from coconut oil impregnated in a compressed expanded graphite matrix. The cubic samples have an edge length of 10 cm. They were placed in an experimental set-up in which hot or cold water can be circulated in thermal contact with four surfaces of the sample. Thermocouples were placed on the surfaces and inside the cubic sample in order to observe the evolution of the temperature affected by the phase changes during heating and cooling processes. The results enable to assess the heat losses of the set-up and the heat transfers between the sample and the water. The dynamic behaviour of the PCM sample can also be approached in order to characterize the material. Its integration in a PCM storage tank will help deploying solar AC systems and act for decarbonisation of the air-conditioned building sector.

INTRODUCTION

TES (Thermal Energy storage) technology has been widely used for dealing with fluctuations in energy demand and supply gaps [1, 2]. Sensible Heat Storage (SHS) and Latent Heat Storage (LHS) can be used depending on the need [3]. The combined thermal energy storage of SHS and LHS has the greatest potential to store heat and can achieve good thermal performance [4, 5]. The LHS material undergoes phase changes involving the same high energy amount from solid to liquid and liquid to solid, called charging and discharging process [6]. Thanks to LHS, the Phase Change Material (PCM) enables to store the highest energy amount per volume unit [7]. Other advantages are chemical stability, suitable phase change temperature depending on the PCM chosen and reasonable price [8]. PCM technology has developed very rapidly in the world in various fields and applications, such as passive cooling for electronic devices, energy conservation in buildings. The use of PCM can minimize peak cooling loads, allow the use of smaller HVAC technical equipment for cooling, and can keep indoor temperatures within a comfortable range due to smaller indoor temperature fluctuations [9].

Pure PCMs can be classified in two categories: organic and inorganic PCMs [10]. Mixtures of organic and inorganic components can also be produced. Within organic substances, paraffins and fatty acids are the most commonly used. They show a high latent heat and a wide range of phase change temperatures. Hydrated salts are the main substances among inorganic substances. They are usually implemented with water for negative temperature heat storage.

Thermal cycle testing has the objective of assessing the thermal stability of the PCM before being implemented in a real application. Repeated heating and cooling, provoking repeated melting and solidification of PCM, can slowly cause PCM quality degradation [11, 12, 13]. Several researchers who have carried out thermal cycle tests and have designed their own thermal cycle test equipment such as that conducted by Karaipekli and Sari, 2008 using a thermostatic bath can produce 5000 cycles [14]. Then Huang, Lu et al., 2013 developed a thermal cycle test equipment based on two thermostatic bath setups and was able to produce 1000 cycles [15]. Sharma and Shukla, 2015 used a

cooling chamber and were able to produce 1200 cycles [12]. In addition, Zhang and Dong, 2017 also used a thermostatic bath and were able to produce 10,000 cycles [16]. The number of cycles achieved in the thermal cycle test depends on the ability of the heating and cooling elements of the appliance and the temperature difference between the melting point and freezing points of the PCM.

A previous publication presented a solar PV air-conditioning system for a net-zero energy hotel using PCM [17]. The PV field produces electricity during the day for a chiller that provides cooling energy to the building plus stores cold in the PCM reservoir for nocturnal cooling loads. Based on this operation strategy, it is necessary to study the behaviour of the PCM during thermal cycles. In this article, the development of a thermal cycle test tool for PCM samples is presented and the first results are analysed.

MATERIALS AND METHODS

Because of interesting commercial assets, the PCM chosen is a eutectic mixture of fatty acids derived from coconut oil. The detailed thermal properties are shown in Table 1 [17]. It is a natural vegetable product and commercially well-received. Hotel guests would likely be disappointed if the PCMs were made from paraffin, mainly from petroleum distillation. The main drawback of PCMs is their low thermal conductivity, which affects thermal diffusivity and, in practical terms, the time required to melt or solidify the material. One of the cheapest solutions seems to be the use of EG. EG can also be compressed in one direction (z-direction) to form compressed expanded graphite (CEG), creating anisotropy inside the structure. The storage system is made up of PCM impregnated inside an EG matrix. However, the carbon loading and the configuration of the storage system are important issues. The time limit is a complete melting or solidification in less than 6 hours. The rest of the night, cooling is carried out by a high ventilation rate during the coldest hours of the night. The objective of a finite differences simulation model was to determine a minimum thermal conductivity associated with a thickness of EG-PCM composite with different carbon loadings and different storage system configurations to meet the criterion of a melting time of less than 6 hours.

TABLE 1. Thermal properties of PCM

Properties	Value
Fusion temperature	16°C
Latent heat	140 kJ.kg ⁻¹
Solid and liquid specific heat	2000 J.kg ⁻¹ K ⁻¹
Solid and liquid density	900 kg.m ⁻³
Solid and liquid thermal conductivity	0.18 W.m ⁻¹ .K ⁻¹

The air conditioning system studied runs on solar PV energy during the day. Thermal energy storage is preferred to electrochemical batteries. The excess electrical energy is used to produce and store cold under the form of latent heat in a PCM. The use of a PCM is a necessary solution to reduce the storage volume. During the early hours of the night, the storage system will release cold from the distribution network that supplies the terminal units in the hotel rooms. During late-night, the cooling energy will be supplied freely by a high ventilation rate during the night. The thermal inertia of the building must also help limit the increase of indoor temperature due to internal heat gains. Figure 1 shows the system to be developed and the placement of the PCM.

The synthesized sample of coconut oil with expanded graphite is in the shape of a square with a length of 100 mm on each side. The sample is made in layers and compressed slowly to produce a cube sample shape with a size of 1000 cm³. This cube-shaped sample will be cycle-tested by providing alternatively heating and cooling using a circulating water heat exchanger. The thermal cycle test equipment developed in this research is based on circulating water around the sample. The design of the cycle test equipment is cheap, compact, and easy to maintain. The design of the box where the test sample is placed can be seen in Figure 2. The box is divided into 3 parts, namely inlet, cartridge, and outlet. The inlet and outlet are where the water flow is conditioning before it enters the cartridge. The inlet and outlet are designed with 6 mm cube-shaped holes surrounding the entire cube blanket of the sample. The design of this hole aims to focus so that the water can flow precisely in the area to be tested for the cycle. The cartridge section is a place to put the PCM sample to be tested. The cartridge consists of a 1000 cm³ space for the sample, a corrugated plate, which is an aluminium passage through which water circulates, and insulation that aims to maintain the desired temperature.

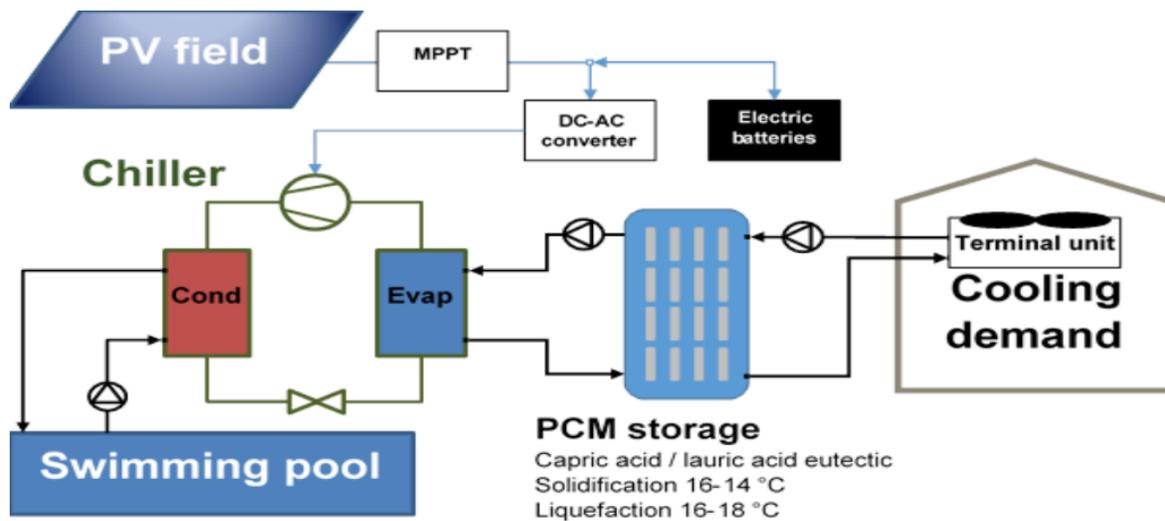


FIGURE 1. Scheme of the solar cooling system with PCM storage [17]

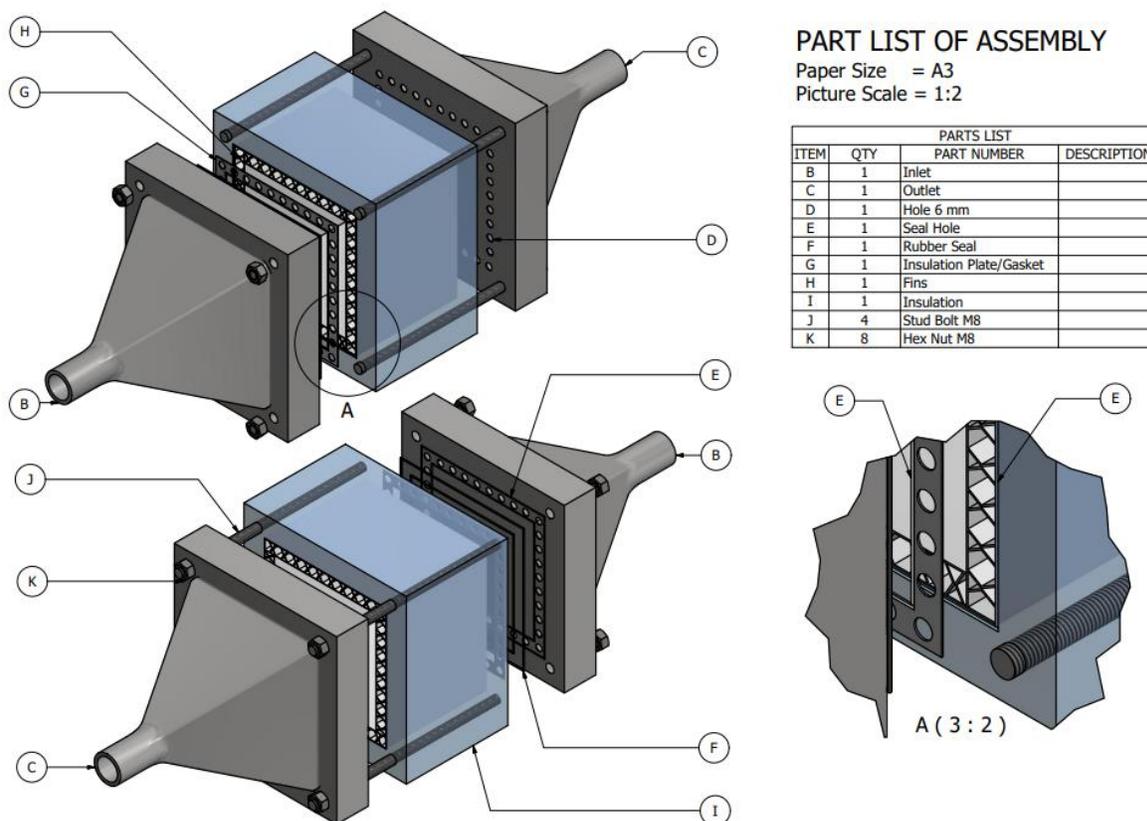


FIGURE 2. Design of box sample

The main components of this cycle test equipment are the Circulating Thermostatic Bath (CTB), a sample box with water passage for circulation, and a data logger to record the test results. In more details, the experimental setup in this thermal cycle test equipment is shown in Figure 3. This setup uses two Circulating Thermostatic Baths (CTB), which provide hot and cold water according to the desired system. Before entering the sample box, there is a flowmeter

and a pricking with a thermocouple that measures the flow rate and the temperature of the water entering the box. In the box, a measuring instrument is installed, namely a type K thermocouple that is connected to the national instrument (NI) data logger. The installed thermocouples will show the behaviour that occurs inside the sample when it is submitted to heating and cooling. From this result, the time duration required for the sample to reach its melting point and freezing point will be assessed. After passing through the cartridge box, the water will exit through the outlet and return to the CTB. The pipe is equipped with a valve that aims to control the water that you want to enter into the system.

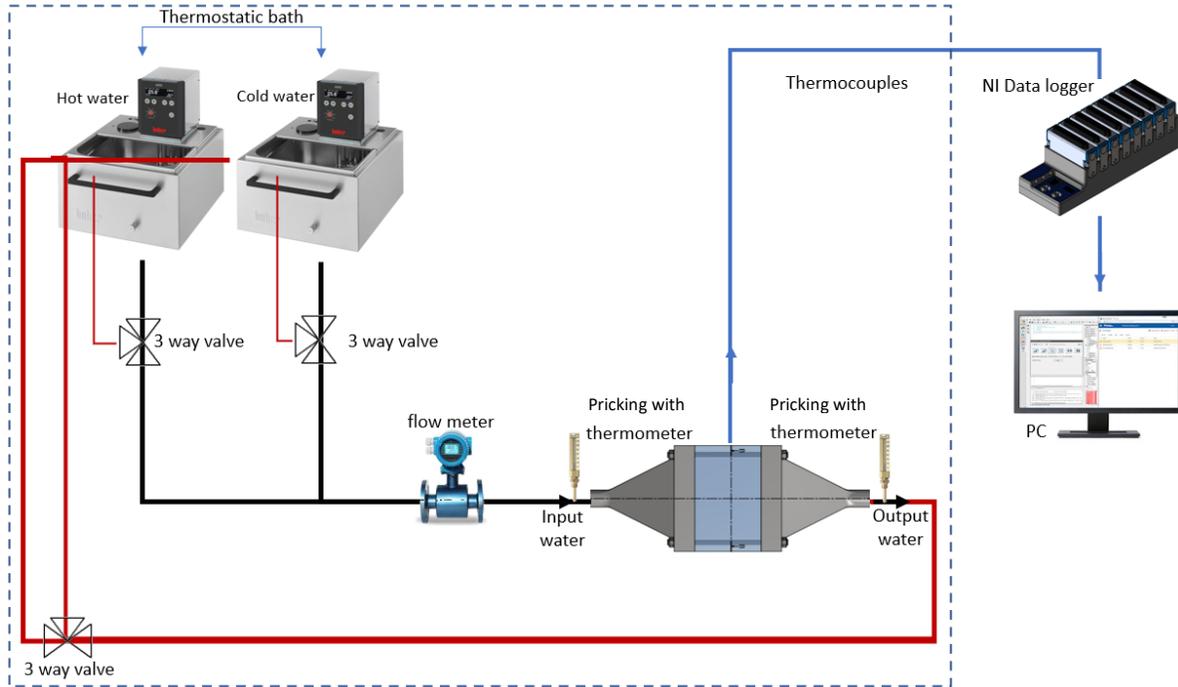


FIGURE 3. Experimental set up of thermal cycle test

Thermal cycle tests were carried out by circulating alternatively hot and cold water along four surfaces of the PCM sample. The inlet water was maintained at 30 °C as long as the sample temperature remained cold. When all temperatures converged, cold water at 5 °C replaced instantaneously hot water by switches of the three-way valves. The next section presents the temperature evolutions that were measured in the very first tests experimented on this set-up.

RESULTS AND DISCUSSION

Figure 4 shows the first temperature measurements obtained with this experimental set-up during a series of three heating-cooling cycles. Heating and cooling stages have the following durations: 700 s heating, 500 s cooling, 1200 s heating, 1000 s cooling, 500 s heating and 400 s cooling. The cooling stages are generally shorter than the heating stages because of the higher absolute temperature difference between the phase change temperature and the heat transfer fluid's temperature.

According to the evolution of temperature at the centre of the cube (sample), the melting temperature is around 18 °C and the solidification temperature is around 18°C, which results in a very small gap. This is an advantage for the specific eutectic mixture of fatty acids chosen as a PCM.

When one stage is long, the phase change is supposed to be completed in a higher number of elements of the sample volume. In this test, short phase durations generate a quicker evolution in the subsequent phase suggesting that the previous phase change was not completed. Longer stages than even 1200 s (20 minutes) should be planned in future tests.

During a heating phase, the inlet temperature is the highest, the outlet temperature is the second highest. The difference between the two corresponds to the energy stored and given back by the sample corrected by the heat losses.

With the water flow rate was equal to 0.5 l/min, the average calculated energy amount stored in this sample is around 64 kJ/kg, which is lower than the expected value presented in table 1 because of the compressed expanded graphite matrix that does not store as much energy and because of the manufacturing defaults of the sample.

The differences between the temperatures on right, left, top and bottom surfaces is not negligible. They can be due to the difficulty of implementing the thermocouples in the exact same way on each surface or to unbalanced water flows on each side of the cube. In spite of the external insulation that was carefully put in place, perturbations may also be brought by the instability of the room temperature (outside box).

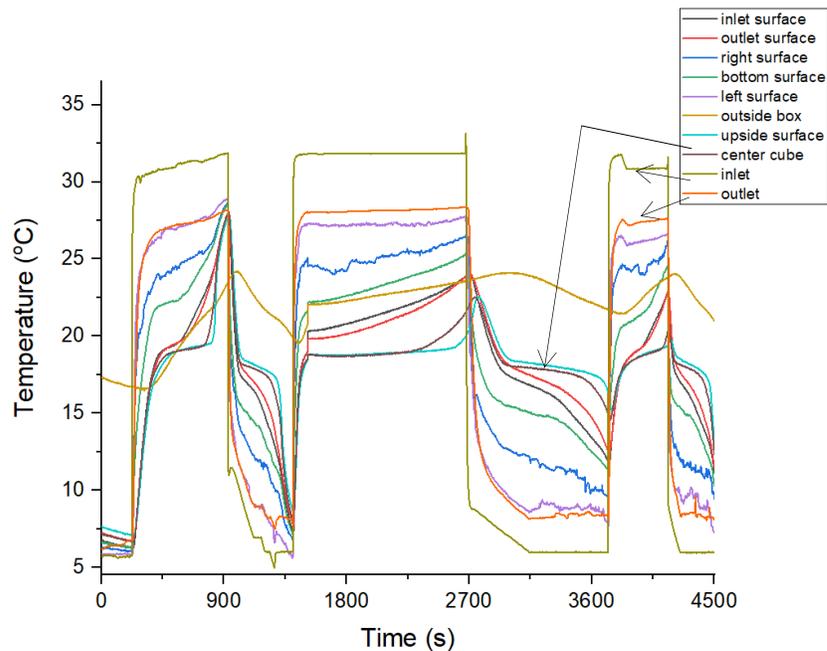


FIGURE 4. Evolution of temperatures during the thermal cycle test

CONCLUSION

A sample of a composite material of a eutectic mixture of fatty acids and compressed expanded graphite was developed. The results of the first thermal cycle tests show a relative performance of this composite PCM. The evolutions of temperatures show an effective energy storage with a simple arrangement for a massive production of energy reservoirs for solar air-conditioning systems. More experiments are planned for a better optimisation of the system before deploying it in net-zero energy buildings.

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