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# Some Heat Transfer Data for a Mannitol Derived Phase Change Material

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## Introduction

The use of phase change materials (PCM) for thermal energy storage facilitates the use of solar systems even at low solar radiation periods, or the storage of surplus discarded thermal energy, available from any other type of source or plant. The greenhouse heating is a typical situation where this kind of energy storage is rather useful [1]. The application of PCM's in domestic heat water production from solar energy is another [2]. Sioshansi and Denholm [3] analyzed the economic impact of the introduction of a thermal energy storage system in concentrated solar energy plants, while Nithyanandam e Pitchumani [4] carried out a detailed economic analysis of the use of phase change materials in concentrated solar plants. The use of phase change materials (PCM) is an economic advantage as it reduces the number and size of the storage reservoirs [5]. It is a most promising solution because it allows a high storage density and an almost isothermal operation [6]. There are many problems with the PCM's, namely due to their low thermal conductivities, low chemical stability, their corrosion capacity towards the storage reservoir materials and large volume variations associated to the change of phases. But new technological developments on the synthesis of new materials are leading to new future promises [6].

The present study concerns the determination of heat transfer coefficients for the design of a concentrated solar energy plant requiring a PCM thermal energy storage. It is part of a set of experiments, where several PCM's were tested in order to obtain heat transfer values [7-9].

## Testing

The heating experiments for the phase change material (PCM) under analysis were carried out in a laboratory installation where hot thermal oil, the Therminol 66, transferred heat towards the PCM under analysis, which was placed inside a set of three transversal pipes with a slight slope to the horizontal. Two mass flow rates of the thermal oil were used in the experiments. During the PCM cooling period, the circulating thermal oil was cooled by a water cooled shell and tube heat exchanger. A quick reversal of the operating conditions of the laboratory set-up could easily be achieved, and the heating and cooling cycles of the PCM could be implemented in a straightforward manner. Figure 1 presents a global scheme and a picture of the installation. During the PCM fusion process the thermal oil was heated in the heater A then it was pumped and sent to the test exchanger D.

The Therminol 66 was chosen because it was intended to be used in a future solar plant operating with the PCM under analysis.

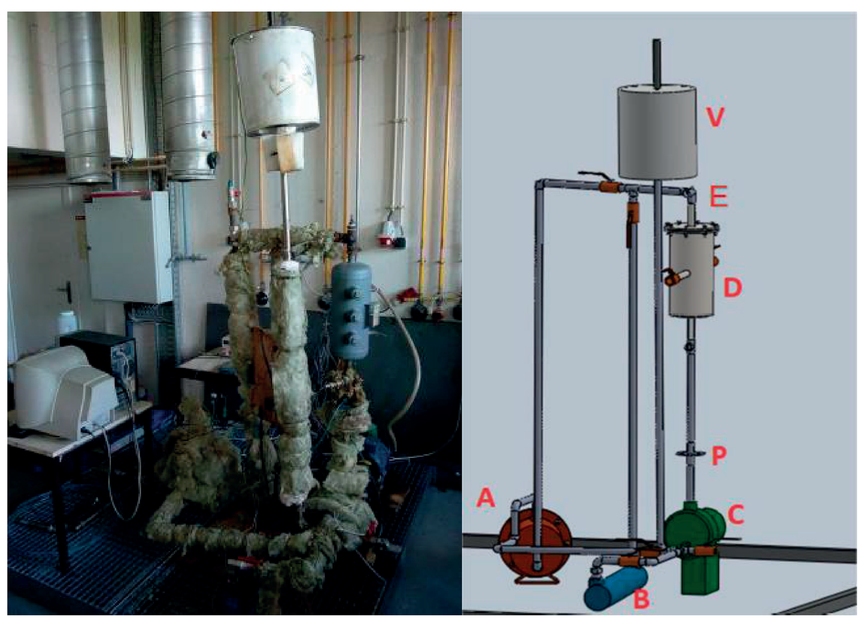


Fig. 1. Picture (left) and scheme (right) of the experimental setup.
A - Thermal oil electrical heater; B - Cooling heat exchanger;
C - Centrifugal pump; D - Test heat exchanger; E - Air purge;
P - Orifice plate flow meter; V - Expansion vessel.

During the PCM solidification step, the thermal oil was cooled in the shell and tube heat exchanger B and then pumped towards the test heat exchanger D. The mass flow rate of the thermal oil was measured by the pressure drop through the orifice plate P, Figure 1. The laboratory installation was equipped with differential pressure transducers and T type thermocouples as necessary to follow the operating process. The computer based data acquisition system is composed by two USB connected interface boards from Measurement Computing and their operation was controlled by the DASYLab software.

Table I. - Properties of Plus ICE A164 as supplied by the manufacturer

| Phase change temperature, °C | Density, kg/m$^3$ | Latent heat, kJ/kg | Specific heat, kJ/(kg K) | Specific energy, MJ/m$^3$ |
|---|---|---|---|---|
| 164 | 1500 | 290 | 2.42 | 435 |

Table II. - Thermal properties of Plus ICE A164 as determined by Trhlikova et al. [10]

| Temperature, °C | Phase | Thermal diffusivity mm$^2$/s | Thermal conductivity W/(m K) | Specific heat, kJ/(kg K) |
|---|---|---|---|---|
| 30 | solid | 0.054 | 0.06 | 0.68 |
| 100 | solid | 0.049 | 0.18 | 2.45 |
| 260 | liquid | 0.078 | 0.24 | 2.07 |

The heat exchanger used in the experiments was composed by a single layer of three almost horizontal pipes. The heat exchanger is made of carbon steel with an internal diameter 159.3 mm and an external diameter of 168.3 mm. There is a bundle of three pipes, which will stay approximately in a perpendicular position towards the external thermal oil crossflow.

These pipes have 210 mm length, 48.3 mm of external diameter and 43.1 mm of internal diameter. Figure 2 presents a 3D image of the heat exchanger while in Figure 3 there is a 2D drawing. When placed in the experimental setup this heat exchanger is in a vertically position, Figure 1. In such situation, the transversal pipes have a 5° inclination towards the horizontal to ease the PCM emptying process.

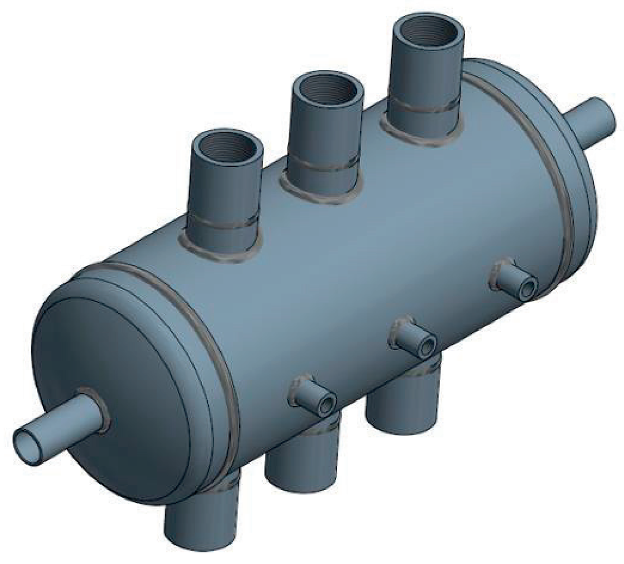

Fig. 2 - 3D image of the best exchanger.

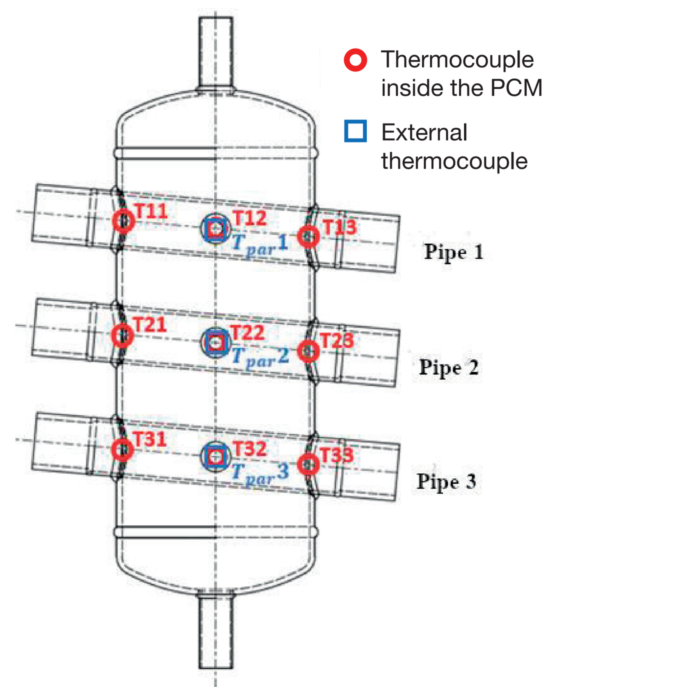


Fig. 3 - Test heat exchanger, in its vertical operating position, indicating the location of the inner (red circles) and outer (blue squares) thermocouples.

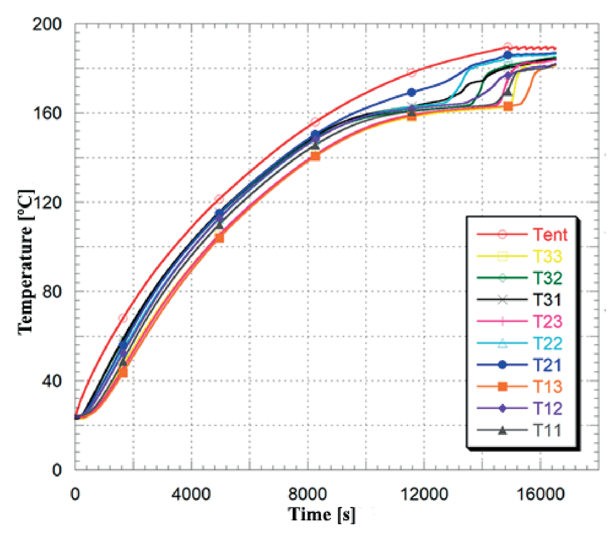


Fig. 4 - Time evolution of the PCM temperature during the heating process for a pump feeding frequency of 50 Hz.

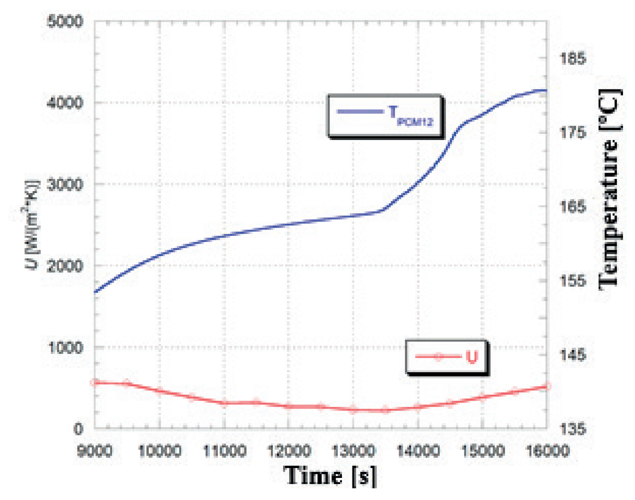


Fig. 6 - Time evolution of the global heat transfer coefficient for a pump feeding frequency of 50 Hz, heating process.

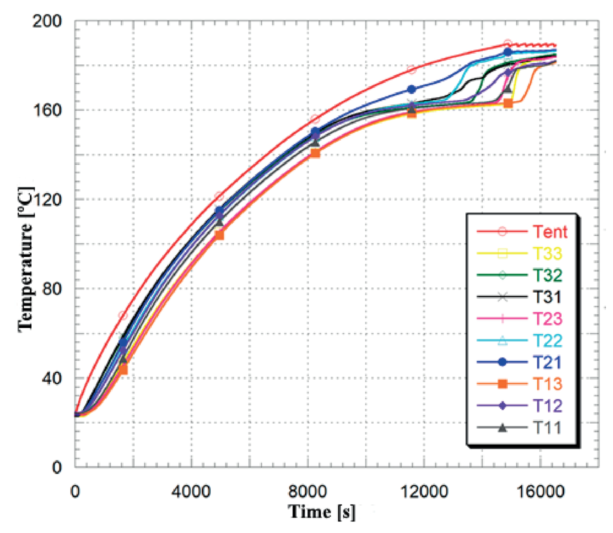


Fig. 5 - Time evolution of the PCM temperature during the cooling process for a pump feeding frequency of 50Hz.

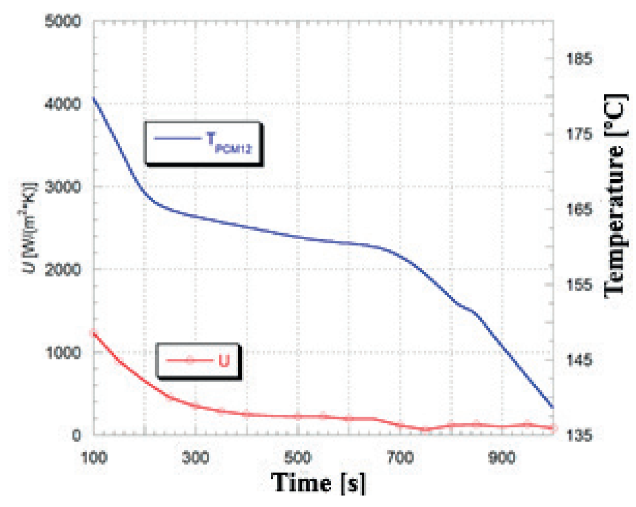


Fig. 7 - Time evolution of the global heat transfer coefficient for a pump feeding frequency of 50 Hz, cooling process.

## Conclusions

The performance of a PCM, a mannitol derivative with the commercial designation of Plus ICE A164, was analysed in a small test heat exchanger composed by a single layer of three horizontal pipes. Using an operating cycle composed by a heating and cooling process an average value of 350 W/(m$^2$ K), for the overall heat transfer coefficient, was determined. Subsequently an average heat transfer coefficient of 415 W/(m$^2$K) for the PCM material was also determined. The time evolution of the PCM heat transfer coefficient is independent from the methodology used for the determination of the external heat transfer coefficient of the pipes containing the PCM.

Table V. - Average values for the PCM heat transfer coefficient.

| Process | Pipe | $\bar{U}$ [W/(m$^2$ K)] | $\overline{h_{int}}$ [W/(m$^2$ K)] Corre-lation | Experi-mental |
|---|---|---|---|---|
| Heating 35 Hz | 1 | 297 | 342 | 353 |
| | 2 | 466 | 550 | 546 |
| | 3 | 341 | 399 | 393 |
| Cooling 35 Hz | 1 | 357 | 432 | 480 |
| | 2 | 339 | 411 | 411 |
| | 3 | 361 | 440 | 434 |
| Heating 35 Hz | 1 | 354 | 406 | 412 |
| | 2 | 354 | 406 | 406 |
| | 3 | 398 | 464 | 458 |
| Cooling 35 Hz | 1 | 300 | 359 | 397 |
| | 2 | 289 | 345 | 345 |
| | 3 | 302 | 361 | 359 |

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