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DETERMINATION OF TERMO-PHYSICAL PROPERTIES OF A PHASE CHANGE MATERIAL

BY

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Abstract. Thermal energy storage with phase change materials (PCM) represents an important technology because of the large quantities of heat stored in small volumes. This work presents a method for determining the thermo-physical properties of phase change materials based on heat flows and temperatures measurements. The phase change material studied is a salt hydrate (water + calcium and potassium chloride + additives) for which were determined the thermal conductivity, specific heat capacity and latent heat.

Key words: PCM; latent heat; thermal conductivity; energy storage.

1. Introduction

Having in view the continuous growth of greenhouse gases emissions and the rising of fossil fuels prices, unconventional energy sources must be used more efficiently and more widely. Over the past decades, in order to increase energy efficiency, scientists have been searching for new forms of renewable

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energy and conservation solutions. One of the possibilities is represented by the developing of thermal energy storage technologies that can be considered as important as the development of unconventional forms of energy (Sharma *et al.*, 2009). Depending on the form under which heat can be stored we distinguish three common energy storage technologies: sensible heat storage, latent heat storage and thermochemical storage.

Phase change materials (PCM) are part of the latent heat energy storage technologies whose main ability is to accumulate large amounts of heat in small volumes. Following the researches in the PCM field a large number of materials were discovered that are accessible for a wide range of temperatures. Based on their chemical composition PCM can be classified into three categories: organic compounds (paraffins, fatty acids, esters, glycols, and alcohols), inorganic compounds (salts hydrate, metals) and eutectic compounds (mixtures) (Baetens *et al.*, 2010).

2. Objectives

The aim of this study was to determine the thermo-physical properties, by experimental measurements, of a PCM that represents a mixture of salt hydrates (water + calcium and potassium chloride + additives) contained in a rectangular plastic box with the characteristics presented in Table 1. Measurements were made in the Civil Engineering and Environmental Laboratory (LGCgE), University of Artois, France.

Table 1
PCM Sample Characteristics

PCM	$Ll\delta$ m	ρ kg/m^3	m_s kg	m_{PCM} kg
Salt hydrates (water + calcium and potassium chloride + additives)	0.21 × 0.14 × × 0.025	1,646	1.21	1.10

3. Working Method

To determine the thermo-physical parameters of the material were conducted measurements of heat fluxes and temperatures on the sample surfaces during the process of melting/solidification of the material.

4. Experimental Device

Experimental device, shown in Fig. 1, consists of two heat exchangers plates connected to the thermostatic baths to ensure the required thermal conditions. Temperature measurement were performed with type T (copper-constantan) thermocouples, tolerance class one (±0.5°C between –40°C and 125°C). Heat flows were measured using heat flux sensors with a sensivity of about 123 μV/W/m^2. The acquisition of the experimental data was performed with a time step of 10 sec., with a data acquisition station connected to a computer from which were controlled the thermostatic baths.

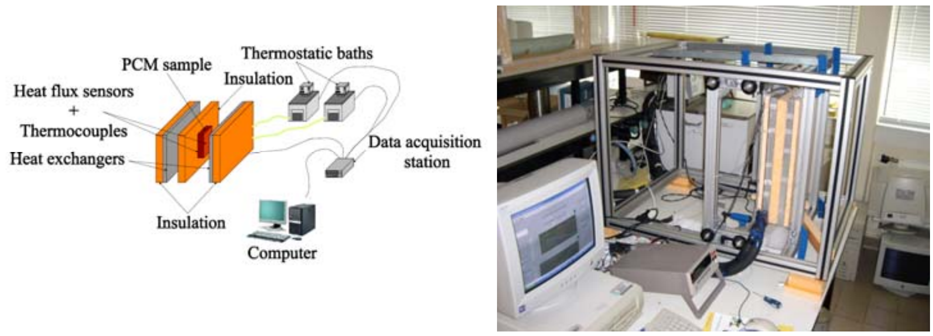

Fig. 1 – Experimental device (general view).

5. Experimental Data Processing

Starting from the experimental results were determined the thermal conductivity, specific heat capacity and latent heat of the PCM. In relation to the melting point of the PCM (27°C) the measurements were carried out at temperatures below 27°C, for the PCM in solid phase (between 9°C and 19°C), and above 27°C for the PCM in liquid phase (between 31°C and 41°C).

5.1. Thermal Conductivity

Thermal conductivity was determined depending on the sum of heat fluxes and the temperature difference using relation (Zalewski *et al.*, 2010; Lassue *et al.*, 1995)

$$k = \frac{\sum \varphi\delta}{2\Delta\theta}. \qquad (1)$$

The used method involved simultaneous measurements of heat fluxes and temperatures on both sides of the sample that is subjected to a temperature gradient generated by the two heat exchangers plates. Compared with conventional methods of determining the thermal conductivity in stady state, the actual used mehod it’s four time faster (Zalewski *et al.*, 2010).

For the PCM in solid phase we obtained an average thermal conductivity of 0.45 W/m.K and for the liquid phase of the PCM an average thermal conductivity of 0.76 W/m.K.

5.2. Specific Heat Capacity

The heat capacity of the material was determined starting from the determination of the total heat accumulated by the material between the imposed temperatures. Relation

$$Q = \int_{\theta_{\text{initial}}}^{\theta_{\text{final}}} \Delta\varphi \mathrm{d}t = C\left(\theta_{\text{final}} - \theta_{\text{initial}}\right), \tag{2}$$

gives the total amount of heat accumulated by the material, with: C – heat capacity, [J/m^2.K]; $\Delta\varphi$ – heat flux difference, [W/m^2]; θ_{final} – final temperature, [°C]; θ_{initial} – initial temperature, [°C].

Relation

$$C_m = \frac{C}{\rho\delta} \tag{3}$$

was used to determin the specific heat capacity per mass

Specific heat capacity was determined for the two states of evolution of the PCM (solid/liquid) during four cycles (melting on cycles 1 and 3, solidify-cation on cycles 2 and 4).

During the determination of the specific heat capacity of PCM in solid state the evolution of heat fluxes and temperatures over the four cycles are represented in Fig. 2 and the results are presented in Table 2.

Table 2
Specific Heat Capacity of PCM in Solid Phase

Cycle	1	2	3	4
θ_{initial}, [°C]	9.28	19.33	9.28	19.29
θ_{final}, [°C]	19.34	9.26	19.33	9.28
C_{mS}, [J/kg.K]	1,523.58	1,532.15	1,522.38	1,538.06

For PCM in liquid phase the results obtained for the specific heat capacity are summarized in Table 3 and the evolution of heat fluxes and temperatures is represented in Fig. 3.

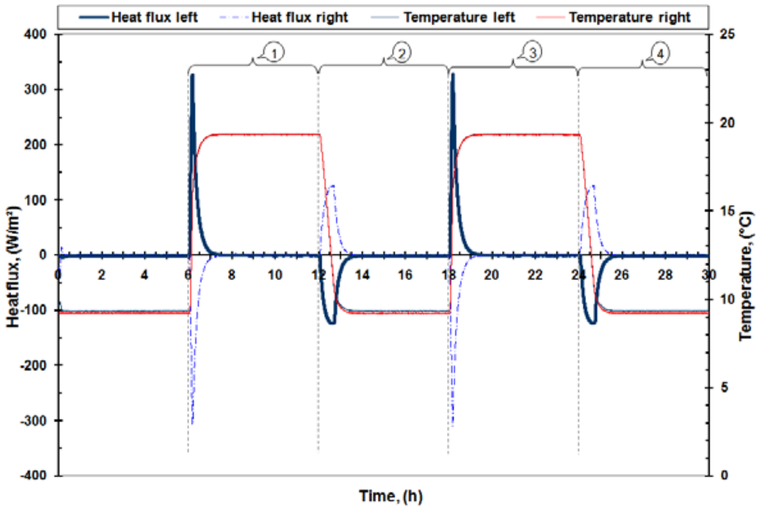

Fig. 2 – Heat fluxes and temperatures evolution at the determination of the specific heat capacity for PCM in solid phase.

Table 3
Specific Heat Capacity of PCM in Liquid Phase

Cycle	1	2	3	4
θ_{initial}, [°C]	31.37	41.43	31.36	41.45
θ_{final}, [°C]	41.44	31.36	41.44	31.37
C_{mL}, [J/kg·K]	2,633.75	2,524.82	2,513.22	2,489.53

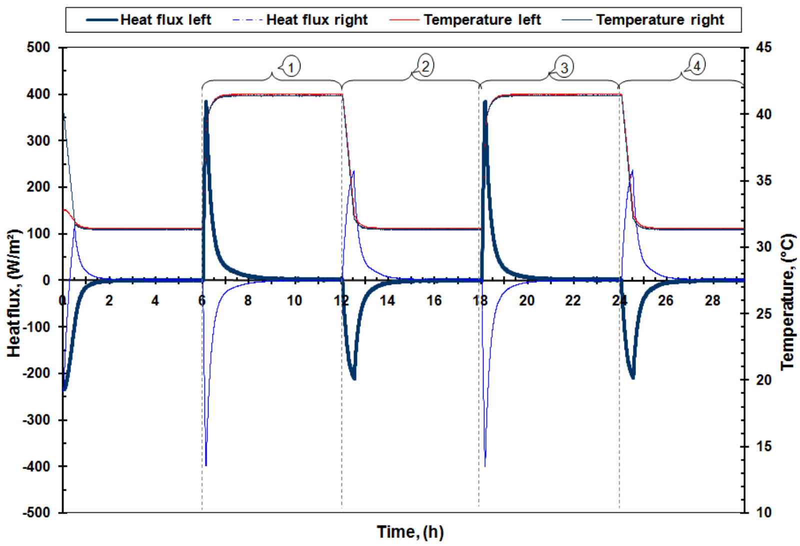

Fig. 3 – Heat fluxes and temperatures evolution at the determination of the specific heat capacity for PCM in liquid phase.

Based on the values obtained above it results an average specific heat capacity of 1,528.96 J/kg.K for solid phase and an average specific heat capacity of 2,540.33 J/kg.K for liquid phase. These results were used to determine the latent heat of the PCM.

5.3. Latent Heat

Latent heat was determined for temperature variation between 9°C and 50°C during the four cycles of evolution of the PCM (melting on cycles 1 and 3, solidification on cycles 2 and 4). Relation

$$Q = \frac{1}{\rho\delta}\int_{t_i}^{t_f} \Delta\varphi \mathrm{d}t \tag{4}$$

gives the total energy stored by the material between the temperature limits. The latent heat was determined from relation (Zalewski, 2010)

$$Q = Q_{\text{sens.}} + \lambda = (mC_{mS}\Delta\theta_S) + (mC_{mL}\Delta\theta_L) + \lambda, \tag{5}$$

with: $Q_{\text{sens.}}$ – sensible heat, [J/kg]; C_{mS} – specific heat capacity for PCM in solid phase, [J/kg.K]; C_{mL} – specific heat capacity for PCM in liquid phase, [J/kg.K]; $\Delta\theta_S$ – temperature difference for PCM solid phase, [°C]; $\Delta\theta_L$ – temperature difference for PCM liquid phase, [°C]; λ – latent heat, [J/kg].

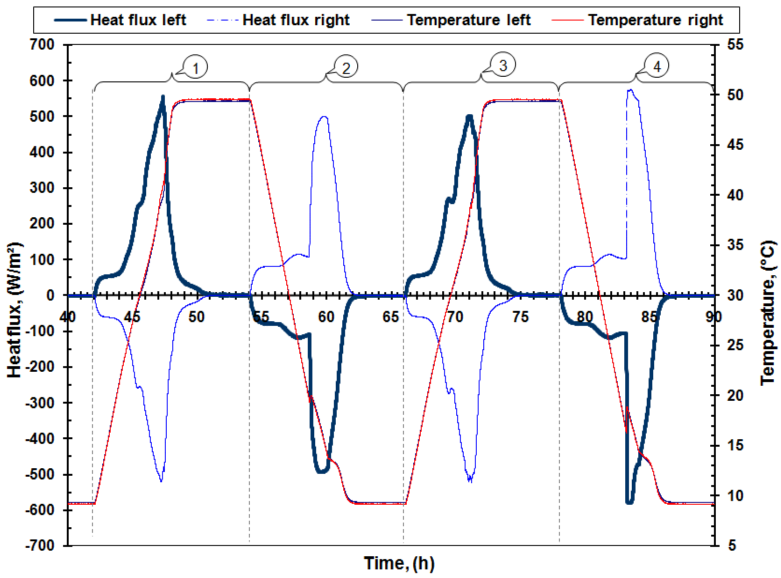

Fig. 4 – Heat fluxes and temperatures evolution at the determination of latent heat of the PCM.

Heat fluxes and temperatures evolution at the determination of latent heat is represented in Fig. 5 and the results for the latent heat are presented in Table 4. The average latent heat obtained is λ = 131,541 J/kg.

Table 4
Latent Heat of the PCM

Cycle	1	2	3	4
$\theta_{initial}$, [°C]	9.56	49.42	9.27	49.46
θ_{final}, [°C]	49.47	9.27	49.46	9.26
λ, [J/kg]	129,499	133,997	129,759	132,910

6. Conclusions

A method to determine the thermo-physical properties of a phase change material starting from experimental measurements of heat fluxes and temperatures is presented, continuing with processing and interpretation of these measurements. The obtained results for the PCM studied in this paper shows us that this material has feasible thermo-physical properties for use as thermal energy storage medium and it can be used in applications for heating and cooling buildings.

Thermo-physical properties obtained through this method for phase change materials are very important for studying and simulating their behavior.

Notations

C – heat capacity, [J/m^2.K];
C_m – specific heat capacity per mass, [J/kg.K];
k – thermal conductivity, [W/m.K]
L – lenght, [m];
l – width, [m];
m – mass, [kg];
λ – latent heat, [J/kg];
φ – heat flux, [W/m^2];
ρ – density, [kg/m^3];
δ – thickness, [m].

Indexes

m – mass;
PCM – phase change material;
s – sample;
S – solid phase;
L – liquid phase

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DETERMINAREA PROPRIETĂȚILOR TERMOFIZICE ALE UNUI MATERIAL CU SCHIMBARE DE FAZĂ

(Rezumat)

Stocarea energiei termice utilizând materiale cu schimbare de fază reprezintă o tehnologie eficientă datorită cantității mari de energie termică acumulată în raport cu volumul. Se propune o metodă de determinare a proprietăților termofizice a materialelor cu schimbare de fază pornind de la măsurări de fluxuri termice şi temperaturi. Materialul cu schimbare de fază, ce face obiectul studiului, este o sare hidrată (apă + clorură de calciu şi potasiu + aditivi) pentru care au fost determinate conductivitatea termică, capacitatea calorică specifică şi căldura latentă.