Influence of the location of the phase-change material on heating and cooling the heat-insulating layer

Mikhail Nizovtsev*, *Vladimir* Letushko, and *Alexey* Sterlyagov

Kutateladze Institute of Thermophysics SB RAS, 630090 Novosibirsk, Russia,

Abstract. The experimental investigation of thermal parameters during heating and cooling of PCM sample placed at different locations has revealed that the phase transition was accompanied by a significant decrease in the growth rate of the PCM temperature when heating, and a slowdown when cooling. The completion of the phase transition upon heating the PCM sample was accompanied by a sharp increase in the heat flux density at the outer surface of the PCM regardless of its location. The produced experimental results on the change of thermal parameters of the PCM depending on its location will be used to verify the calculation model.

1 Introduction

To date, phase change materials (PCMs) are actively used to reduce the amplitude of temperature fluctuations in various technical applications. PCMs are materials, in which reversible phase transitions with thermal energy absorption or release occur [1].

PCMs have been widely used in the construction industry [2, 3]. PCM additives in cement are used in the production of concrete to increase its thermal inertia in a certain temperature range [4]. Wall panels are produced with the addition of paraffin as PCM [5]. While having high thermal insulation properties, lightweight insulation materials have low thermal inertia, which limits their field of use. Using lightweight thermal insulating materials together with PCMs allows increasing significantly the heat-storing properties of thermal insulation due to the latent heat of phase transition, as well as improving significantly the thermal protection characteristics of building envelopes. PCMs are used in the form of additives to lightweight insulation materials to increase the thermal inertia of wall structures [6–8]. Studies have been conducted on using PCMs in building envelopes to prevent overheating of internal spaces in summer [9, 10]. PCM is added to building envelopes either in a macroencapsulated form [11, 12], as well as to materials with a particular porous structure [13, 14], or using micro- and nanoencapsulation [15, 16]. In micro- and nanoencapsulation, various polymeric materials are used as the outer shell of the PCM [17]. Due to the high values of the latent heat of phase transition, PCMs are widely used in various technical applications in energy industry [18]. Thus, the patterns of thermal processes in PCMs can be used when controlling the heat transfer in various energy units. Simulation of thermal processes in PCM requires computational models, which can be verified using reliable experimental data.

2 Experimental setup

To verify the enthalpy model for calculating thermal processes in PCM [19], experimental studies of thermal parameters were carried out for different positions of the PCM layer in the structure. Experimental investigations were carried out using an experimental setup designed at the Kutateladze Institute of Thermophysics, SB RAS. Schematic diagram of the structure, investigated in the experiments, as well as location of thermocouples and heat flux sensors is shown in Fig. 1.

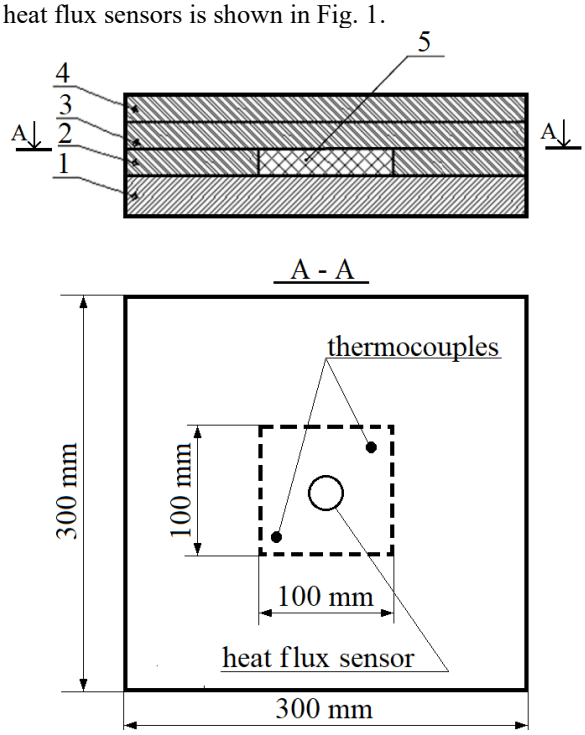

Fig. 1. Experimental setup and location of thermocouples and heat flux sensors: 1 - heated plate; 2 - layer with PCM; 3, 4, - heat-insulating layers of mineral wool; 5 – PCM sample.

* Corresponding author: nizovtsev@itp.nsc.ru

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The heated metal plate was located in the lower part of the investigated structure of 100×100 mm. The metal plate with an internal heater provided uniform heating. As shown in the schematic diagram, a mould of cardboard, which was filled with P-2 grade paraffin as PCM, was placed on its surface. Thus, PCM sample of 100×100×10 mm (h) was constructed, which was retaining its shape during melting. The sample was thermally insulated from the lateral sides by mineral wool (MW). The PCM sample with lateral thermal insulation comprised a 10 mm thick layer 1. Several 10 mm thick layers of thermal insulation material MW were mounted above the plate. One of the layers included a paraffin sample, used as PCM, thermally insulated from the lateral sides. Thermocouples and heat flux sensors were installed between the layers and secured with thermal paste. Temperature measurements were made using chromel-copel thermocouples (type L) with an uncertainty of ±0.2°C. To measure the heat flux, sensors of the PTP-1B type were used (relative measurement error ±5%).

3 Experimental results and analysis

A series of experiments was completed, in which the PCM layer was placed in different positions relative to the heated plate. The experiments were carried out as follows: the plate was heated to a certain temperature, resulting in a phase transition in the PCM sample; then the plate heater was turned off and the system was cooling down spontaneously.

The first series of experiments was carried out with the layers arranged according to the scheme shown in Fig. 1. In the experiment, the plate was heated to a temperature of about 90˚C, after which the heater was turned off and the system was gradually cooling. Figure 2 presents the produced experimental data on the temperature change at the top surfaces of the layers when the PCM layer was placed as shown in Fig. 1. The data show that the temperature of the upper surface of the PCM layer (line 2) increased rapidly, followed by a slowdown in the rate of temperature increase, which was associated with the beginning of the phase transition in the PCM sample.

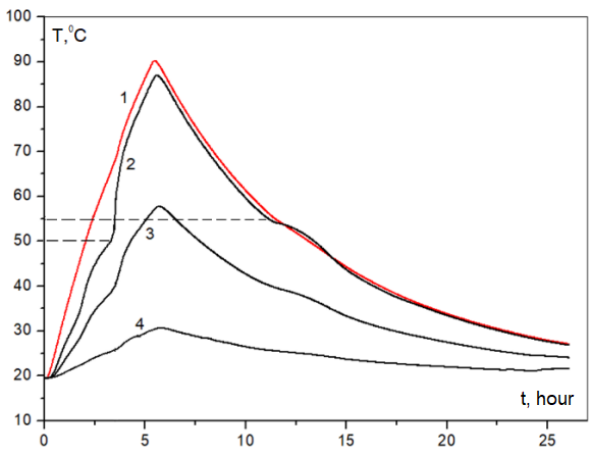

Fig. 2. Temperature variations of upper surfaces of the layers; layer numbering as per Fig. 1: 1 – heated plate, 2 – 1st layer (PCM), 3 – 2nd layer (MW), and 4 – 3rd layer (MW).

When the temperature of the upper surface of PCM layer was exceeding 50˚C, phase transition of paraffin terminated, and PCM surface temperature started to increase sharply again. In the cooling mode, the surface temperatures of the plate (line 1) and the PCM layer (line 2) initially decreased uniformly to about 55˚C, when the reverse phase transition of paraffin from liquid to solid state began, accompanied by heat release and a reduced cooling rate of the PCM layer comparing to the plate. After transition of entire sample of paraffin to the solid state was completed, the rate of further cooling of the plate and PCM sample was practically the same. The phase transition in paraffin has also influenced the temperature change of the upper thermal insulation layers, but in a smoother manner (lines 3 and 4). Completion of the phase transition in paraffin upon heating was also manifested by a sharp increase in heat flux density at the surface of the PCM layer, which was recorded by the heat flux sensor, located on the upper surface of the paraffin sample (line 1 in Fig. 3).

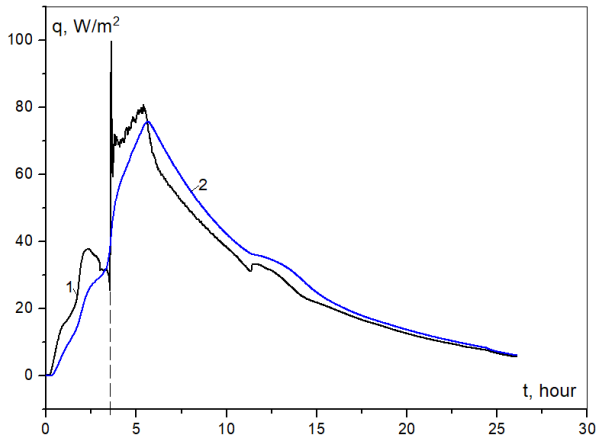

Fig. 3. Change in heat flux density at the upper surface: 1 – 1st layer (PCM), 2 – 3rd layer (MW).

In the next series of experiments, the paraffin layer was moved to the middle position between the MW layers of the same thickness. Figure 4 shows the temperature change at the upper surfaces of the plate and layers when heating the plate up to 125˚C and subsequent free cooling.

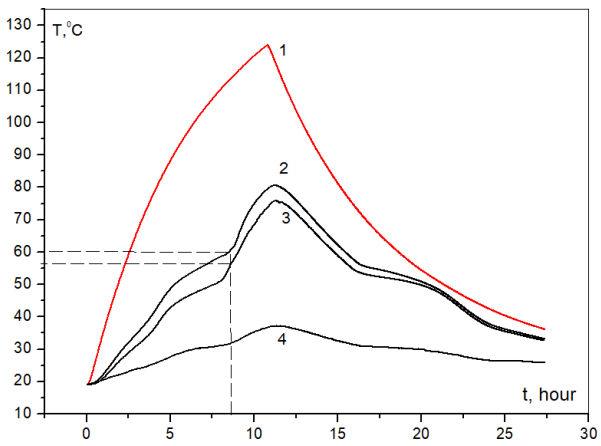

Fig. 4. Temperature variations at the upper surface: 1 – plate, 2 – 1st layer (MW), 3 – 2nd layer (PCM), 4 – 3rd layer (MW).

In Fig. 4, lines 2 and 3 show the temperature change at the upper and lower surface of the paraffin layer. The graph clearly shows the change in the rate of temperature variations in the PCM layer due to the melting of the paraffin when heated, and the solidification when cooled.

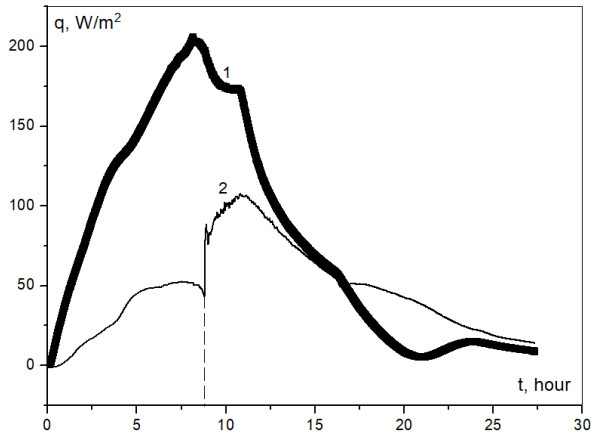

Fig. 5. Change in heat flux: 1 – at the upper surface of the PCM sample; 2 – at the lower surface.

Change in the heat flux density at the bottom surface of the paraffin sample (line 1) and the top surface of a sample (line 2) is shown in Fig. 5. As in the case, considered previously (Fig. 3), the completion of the phase transition in PCM melting coincided in time with a sharp increase in heat flux. During the experiment, this increase was well observed at the upper surface of the PCM sample (Fig. 5), or manifested in a decrease in difference of heat flux density at the lower and the upper surfaces of the PCM sample (Fig. 6).

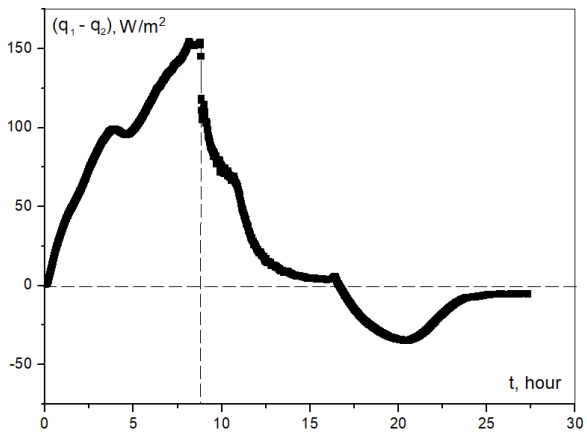

Fig. 6. Difference in heat flux densities at upper q_1 and lower q_2 surfaces of the PCM sample.

As can be seen from the data presented, in the initial period, the difference of heat flux densities between the lower and upper surfaces of the PCM sample increased. Nine hours after the experiment started, a sharp drop in the difference of heat flux densities from 152 to 110 W/m^2 was noted, indicating the completion of phase transition.

To implement the option of placing the PCM as the outer layer, experiments were carried out with the inner layer of MW and the outer layer with PCM. When increasing the temperature of the heated plate to 200˚C, the dependencies of the temperature variations in the PCM layer have shown distinctive features that manifested themselves in slowdown of temperature growth in the phase transition range during PCM melting (Fig. 7) and a sharp increase in heat flux density on the outer surface of the PCM (Fig. 8), or in a sharp decrease of the difference of heat flux densities between the inner and outer surfaces of the PCM (Fig. 9).

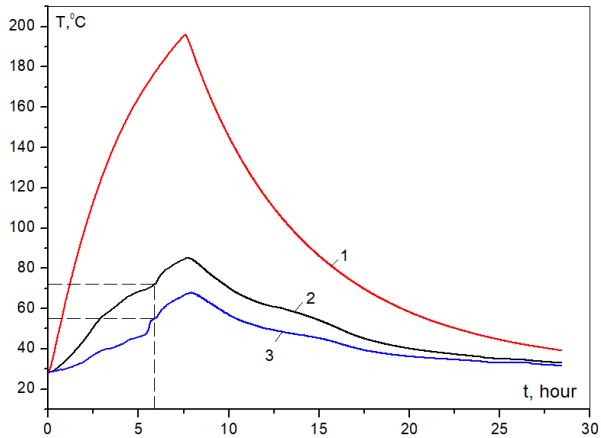

Fig. 7. Upper surface temperature variations: 1 – heated plate, 2 – 1st layer (MW), 3 – 3rd layer (PCM).

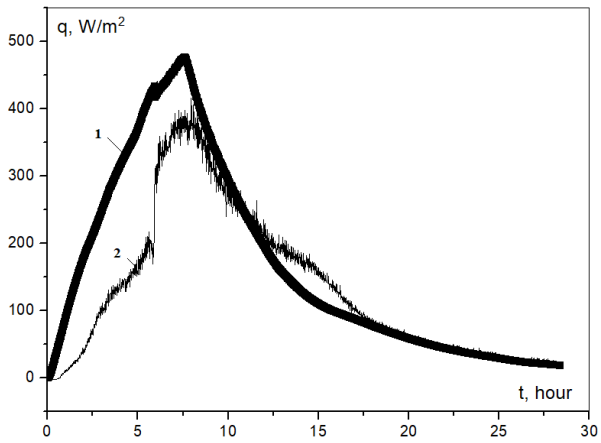

Fig. 8. Variation of heat flux density at the bottom 1 and top 2 surfaces of the PCM sample.

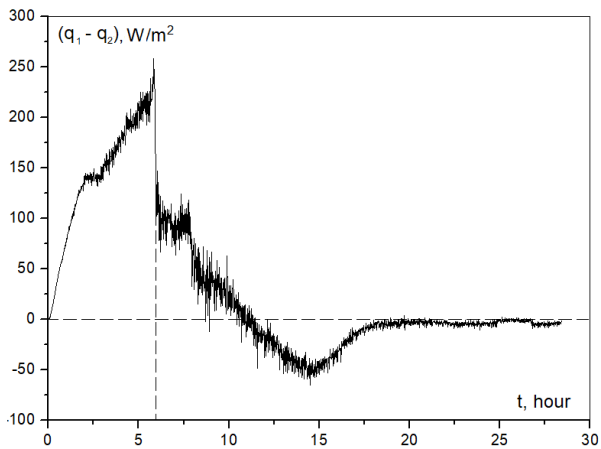

Fig. 9. Difference in heat flux densities at the lower q_1 and upper q_2 surfaces of the PCM sample.

4 Conclusions

The experimental investigation of thermal parameters during heating and cooling of PCM sample placed at different locations has revealed that the phase transition was accompanied by a significant decrease in the growth rate of the PCM temperature when heating, and a slowdown when cooling.

The completion of the phase transition upon heating the PCM sample was accompanied by a sharp increase in the heat flux density at the outer surface of the PCM regardless of its location.

The produced experimental results on the change of thermal parameters of the PCM depending on its location will be used to verify the computational model.

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