# Heat Transfer by Forced Convection from a Vertical PCM Plate

Martin Kolacek, Stanislav Sehnalek
Department of Automation and Control Engineering
Tomas Bata University Faculty of Applied Informatics
Nad Stranemi 4511, 760 05
Zlin, Czech Republic
kolacek@fai.utb.cz , sehnalek@fai.utb.cz

*Abstract:* - The article describes the possibility to obtain stored energy from PCM materials by using forced convection. The PCMs are very popular in many different applications for temperature stabilization of the microclimate inside buildings. The acceleration of releasing the stored energy is important for discharging cycle, which is very difficult to achieve because of the supercooling effect. Forced convection was used as an option for speeding-up the energy release. It is important to know some of the simple relations in fluid dynamics and boundary layer analysis to understand the forced convection heat transfer. Thermal imager was used for visualization of stored energy release. The paper also focuses on boundary layer with forced convection and the flow visualization around the surface of the vertical plate. It is possible to use the stored energy within several cycles. This energy can be used in various ways, such as a device with intermittent heating and cooling equipment. The aim is to develop a device which can be used for cooling or maintaining steady thermal conditions.

*Key-Words:* - Phase change materials; heat transfer; forced convection; natural convection; thermal imager.

## 1 Introduction

Streamline of release of accumulated energy from the Phase Change Materials (PCM) is important part of discharging cycle. The PCM materials are used in many different building applications. It is an effective way to enhance energy efficiency in buildings by increasing the heat capacity of light-weight buildings, especially steel structures and adding more thermal mass to concrete and brick structures. These systems are promising solution to cut down energy consumption by taking advantage of materials with high energy storage capacity to store energy in terms of sensible heat and latent heat. PCMs are distinguished because of their high latent heat capacity which enables them to store a high amount of energy in small temperature intervals, which results in a significant increase in the thermal mass of the building when incorporated into its envelope. [8]

The PCMs materials were used as plates of 5 mm thickness. These materials are used in building structures where they participate on creating stable climatic conditions during a hot day, when the temperature increases inside the building. The stored energy is saved inside the PCMs and during the night, when the temperature drops below the melting point of PCM, the stored energy is released into the surrounding environment. The discharging cycle is dependent on the surrounding temperature and is an important prerequisite for the heat transfer. In many different applications, PCMs are located under cover layer as plasterboard. It is a problem to meet the conditions where the stored energy starts to release. The article describes the differences of heat transfer from specific materials. The main way to release the stored energy was the forced convection, when the panel was blown along one side by the specific diffuser. During the release of energy, the average value of heat transfer coefficient was calculated.

The measurement was performed with two different applications of PCMs. First, a specific thermal device composed from 12 PCMs plates was used and another test was done with just PCM plates. In both cases the means of forced convection were measured and their effect on the convective surface property.

## 2 Methods

Equipment used for research is located in Laboratory of Environmental Engineering at the Faculty of Applied Informatics, Tomas Bata University in Zlín, Czech Republic. The first system consist of thermal accumulative panels with active heating or cooling. Inside the panel are imposed 12 PCM plates. The PCM material is based on paraffin wax and its melting point is around 22 °C. The thermal storage materials are used not only as a heat source but also to increase the heat accumulation parameters of building. This material has a specific parameters, such as heat capacity which is dependent on temperature. For calculation was used the average value of the heat capacity. Another measurement was performed on the basic PCM plate which was located in double calorimeter chamber, where precise climate condition were maintained during both forced convection and natural convection tests.

The forced convection on the PCM panels was done by using a fan with a special diffusers. The diffusers had to be designed for the best flow distribution on the panel surface. For the verification of this parameter, a simulation model had to be created, which included different outlets and a regulatory element. The velocity profile was measured by vane anemometer and within stable conditions in the laboratory. The visualization test was performed by smoke test and the helium bubble generator which produces neutrally buoyant, helium filled soup bubbles in a controllable size range of 1/16” to 1/4” diameter. This bubbles also follow flow streamlines. Thus, large scale of flow patterns can be defined using these bubbles. [7]

## 2.1 Heat Recovery from PCM Panels

The main priority of heat recovery are convective and radiative surface parameters of panels. Object of the research was identify a heat transfer coefficient. The changes of this parameters let us to get the stored heat more effectively. The panel releases a heat when the temperature of panel drops to 21°C in common usage of these PCM materials. When PCM materials is used as a heater is difficult to obtain a heat from material, therefore was done a different adjustment of surface parameters.

The part of the heat recovered from PCM represents the thermal radiation, as the energy of the radiation field is transported by electromagnetic waves. In this case, the emissivity was very important. The property provided an estimation of how efficiently a surface emits the energy relative to blackbody. The PCM material is covered by aluminum foil where the value of emissivity is very low and the part of heat recovery by thermal radiation is low. This problem was described in article [10].

The main issue of cooling the PCMs is the supercooling. This is the effect when the temperature of storage material needs to go significantly below the melting point, until the material begins to solidify and starts releasing heat. If the temperature is not reached, the PCM will not solidify at all and thus only store sensible heat. [12]

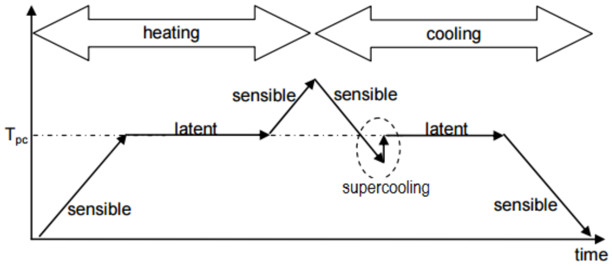

Fig. 1. Schematic temperature change during heating and cooling of PCM, supercooling [12]

The Fig. 1. shows schematic temperature during the charging cycle with supercooling effect. PCMs are based on paraffin show beneficial storage density with respect to mass, melt and solidify with little or no supercooling issue.

Mechanism of forced convection is complicated since it involves fluid motion as well as heat conduction. The higher the velocity the higher the heat transfer coefficient is. The coefficient depends on the fluid properties, roughness of the solid surface and the type of the fluid. In above mentioned cases the smooth surface and stable velocity of fluid was used.

The equations of forced convection describing momentum and energy transfer in free convection originate from the related conservation principles. Moreover, the specific processes are much like those that dominate in forced convection, inertia and viscous forces remain important, as does energy transfer by advection and diffusion. The difference between the two flows is that in free convection a major role is played by buoyance forces. This forces in fact drive the flow. [3]

For the calculation of Forced convection are given the equations:
At any location

$$Nu = 0{,}332(Re)^{1/2}Pr^{1/3} \tag{1}$$

Average Nusselt Number

$$Nu = 0{,}664(Re)^{1/2}Pr^{1/3} \tag{2}$$

Where $Re$ is Reylnods number [-]
$Pr$ Prandtl number [-]

Where the characteristic length employed in the definition of Nusselt number and Reynolds number is the Length of the plate. The heat transfer coefficient, which describes the heat transfer from the material to the surrounding, was calculated by these equations. For ratio of convection to pure conduction heat transfer is given the Nusselt Number in (3).

$$Nu = \frac{h.L}{k} \qquad (3)$$

Where $h$ is the heat transfer coefficient [W.m$^{-2}$K$^{-1}$] $L$ characteristic length scale [m] $k$ thermal conductivity [W.m$^{-1}$.K$^{-1}$]

The Nusselt number is used to characterize the heat flux from a solid to a fluid, the thermal conductivity is for the fluid.

## 3 Results

For comparison of the forced convection and natural convection were performed two measurements and results were compared for the first case in the graph in Fig. 2. The measurement was done on the thermal panel of dimensions 2 x 1.1 x 0.08 m, in a laboratory of Environmental Engineering where the stable climatic condition were ensured. Dimensions of the laboratory are 3 x 8 x 5 m. The air temperature was 22°C and the panel was heated up to 33°C and then retain to cool.

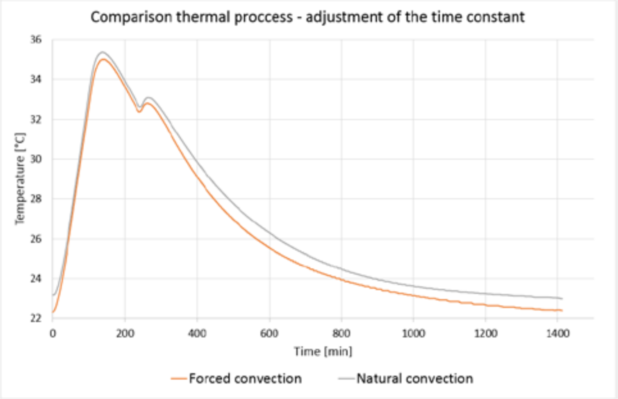

Fig. 2 Comparison of the forced and natural convection

The forced convection caused a change in temperature process inside the panel. Fig. 2 shows the reduction of heat transfer coefficient which caused acceleration of cooling. In Fig. 3 the change of the time constant is evident. Application of these adjustments are important to obtain a suitable solution for proposal a heating equipment using PCM materials. To obtain a precious continuous flow the visualization test was used as a specific measuring equipment. Instead of the fan, a precise airflow 100m$^3$/h equipment was obtained.

Visualization was performed by smoke test to compare the result from those performed by simulation. Another visualization test was done with helium bubbles generator which depicted the exact distribution of airflow. That part of research will be presented in separate article which focuses on the flow profile along the heated vertical PCM panel.

An important parameter is a time constant of the heating equipment. In this case it was the time constant of the thermal panel. The measurement was performed several times to obtain accurate results. The value of time constant of thermal panel was 6,8 hours. Increase of heat transfer coefficient caused the time constant to decrease to a value 4,5 hours (in forced convection case).

| | Heat transfer coefficient [W.m$^{-2}$K$^{-1}$] | |
|---|---|---|
| | Calculated | Measured |
| Natural convection | 8.02 | 8,73 |
| Forced convection | 9.92 | 13,19 |

Table. 1 Heat waveforms inside the panel, heat transfer coefficient, Thermal panel

It is very difficult to obtain a precise parameters with use of forced convection on phase change materials. During the cooling process, the material changes its parameters, especially thermal heat capacity. The heat transfer coefficient is average value appearing in Tab. 1. The values of heat transfer coefficient, which were obtained from measurement of the time constant, were higher than calculated value in Tab.1 primarily by forced convection. The calculation methods are shown in article [10]. It is very difficult to determine the exact value because the flow profile varies in different parts of the panel. During the cooling process the temperature and the heat transfer coefficient drops. When the forced convection was used for cooling of PCM, therefore the PCM releases the latent heat to an ambient temperature less than is the melting point. The issue about forced convection with cooling of PCM represents the possibility to use rechargeable cycle. This application can be used when it is necessary to release the stored energy or the PCM is placed in specific cooling or heating device.

### 3.1 Application of the PCM Plate

Specific test was done in double calorimeter chamber, where two PCM plates and diffusor were installed, to create the forced convection. Dimensions of chamber are 3,2 x 8 x 4,5 m. Between the plates was placed a heat foil which heated PCMs. Surface temperatures on the panel were measured. The surface was covered by white matte foil to obtain a better heat recovery from panel and also to improve a possibility of creating the thermal image. This issue about low emissivity of PCM surface was described in article [10]. In this measurements was used a basic fan airflow of 100m$^3$/h, but the real velocity around the surface was lower than in the first case.

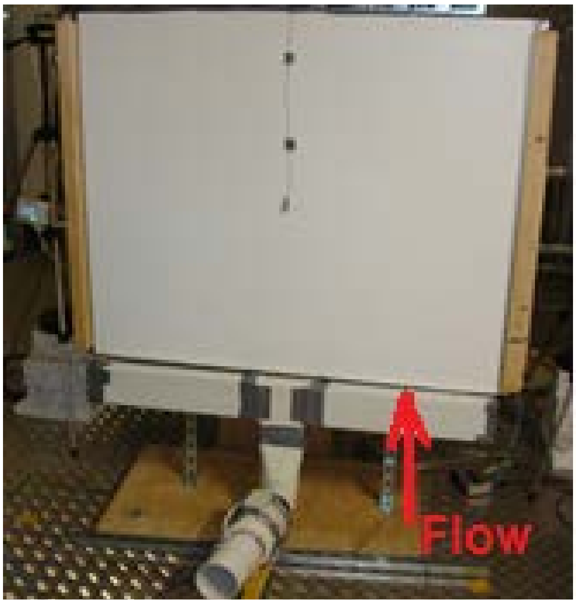

Fig. 3 The measurement object and diffusor

The surface temperature was measured by thermal imager. As depicted in Fig. 6, the temperature field is almost equal. In case of forced convection in Fig. 5 the evident colder bottom part of the panel is evident. Both thermograms were created in the same conditions of surface temperature and also same air temperature.

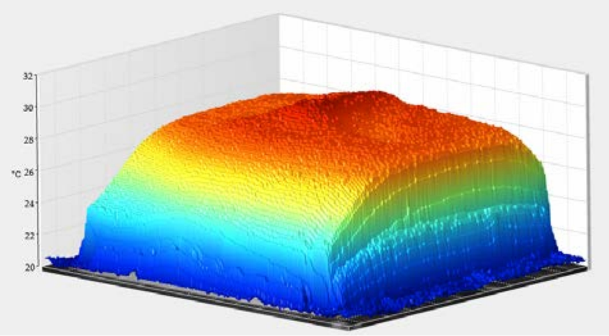

Fig. 4 Thermal field on the surface of the PCM by thermal imager (Natural convection).

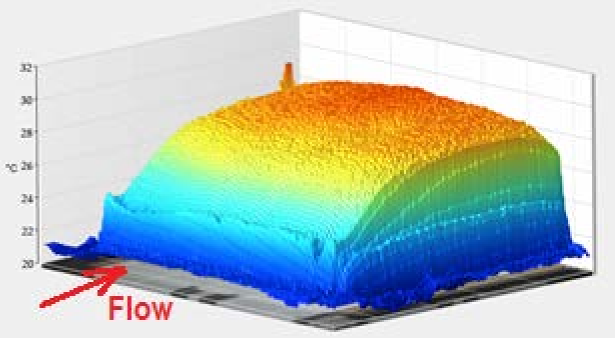

Fig. 5 Thermal field on the surface of the PCM by thermal imager (Forced convection)

The air flow caused the reduction of surface temperature, as visible in Fig. 8. The energy release caused by forced convection was achieved much quicker than by using the natural convection. The PCM plate behaves differently than thermal panel, where is placed 12 PCM plates. Nevertheless these results are very important for applications of simple PCM plates where it will be possible for the air flow the release of energy in either cooling mode or heating mode.

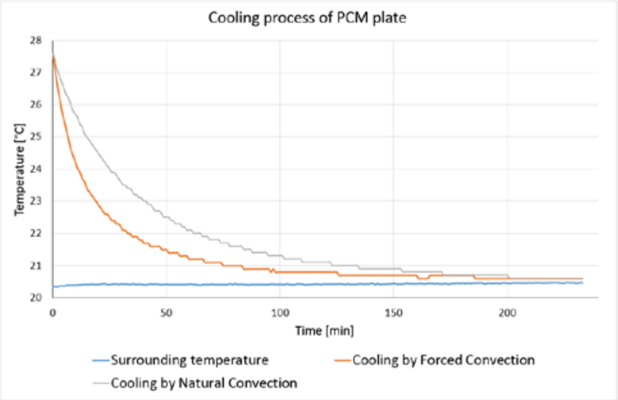

Fig. 6 Cooling process of PCM plate in calorimeter chamber

| | Heat transfer coefficient [W.m$^{-2}$K$^{-1}$] |
|---|---|

| | Calculated | Measured |
|---|---|---|
| Natural convection | 9,26 | 6,67 |
| Forced convection | 10,53 | 14,03 |

Table. 2 Heat waveforms inside the panel, heat transfer coefficient, PCM plate

The results of the heat transfer coefficient shows again the difficulty to determine the exact value of this coefficient. Heat transfer coefficient is a quantitative characteristic of convective heat transfer between a fluid medium and the surface. In both cases was showed that the change of heat transfer coefficient causes rise in release of stored energy from PCM plates. Further research of forced convection in cooling mode of PCMs will be carried on.

## 4 Conclusion

Measurements have been performed on the thermal panel and PCM plate. The thermal panel was measured in the interior of laboratory. The PCM plate was measured in precision double calorimeter chamber. In both applications, the use of the forced convection was studied. It was found that forced convection allows to significantly accelerate the discharge cycle of PCM. For systems with high thermal inertia, like the PCM, sufficient time interval between periodic cycling of stresses must be ensured. The forced convection represents an opportunity to get more discharge cycles during the day. This procedure could therefore be implemented into specific devices which will use the capabilities of stored energy. It will be followed by further research to create a device which will ensure a better climatic conditions with minimal costs.

**Acknowledgement**

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic within the National Sustainability Programme project No. LO1303 (MSMT-7778/2014) and also by the European Regional Development Fund under the project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089 and also by internal grant agency of Tomas Bata University in Zlin no. IGA/CEBIA-Tech/2016/001.

*References:*

[1] Bejan A. *Convection Heat Transfer*. Duke University, Durgam, North Carolina. Wiley 2013. Range:680 p. ISBN: 978-0-470-90037-6

[2] Haaland H.T. *Flow and heat transfer in a radially spreading liquid metal jet related to casting of ferroalloys*. Norwegian University of Science and Technology. Trondheim 2000. Available: http://www.diva-portal.org/smash/get/diva2:125422/FULLTEXT01.pdf

[3] Incropera, Frank P., Dewitt, David P., Bergmann, Theodore L., Ted. Lavine, Adrienne S. *Fundamentals of Heat and Mass transfer. Seventh edition*. John Wilez and Sons USA. 2011 ISBN: 978-0470-50197-9

[4] Lienhard J.H. IV, Lienhard J.H. V. *A heat transfer textbook. Fourth edition*. Phlogiston Press. Cambridge Massachusetts. 2011.

[5] Sehnalek, S. Zalesak, M. Vincenec, J.Oplustil M., and Chrobak P., "*Ground-Coupled Heat Transfer Test Cases as ranking simulation software*," WSEAS TRANSACTIONS on INFORMATION SCIENCES and APPLICATIONS. Volume 12, 2015. ISSN / E-ISSN: 1790-0832 / 2224-3402

[6] ČSN EN ISO 13790. *Energy performance of buildings – Calculation of energy use for space heating and cooling*. Czech Office for standards, Metrology and Testing. October 2009.

[7] Bianca, J.D., Bauver II W.P., McGowan, J.G. *Dynamic Flow model for low-BTU gasification of coal for electric power generation*. 1977. Combustion Engineering, Inc. Power Systems Group, Windsor, Connecticut

[8] Mohammad Saffaria, Alvaro de Graciab, Svetlana Ushak, c, Luisa F. Cabeza. *Economic impact of integrating PCM as passive system in buildings using Fanger comfort model*. Energy and buildings. Volume 112, 15 January 2016, Pages 159-172.

[9] H.R Goshayeshi, F.Ampofo, *Heat Transfer by Natural Convection from a Vertical and Horizontal Surfaces Using Vertical Fins*. Energy and Power Engineering,2009, Pages 85-89. ISSSN online: 1947-3818

[10] Kolacek,M. Zalesak M. "*The parameters of the Thermal panel based on a Phase Change Materials*". International Journal of Materials. Volume 3, 2016. Pp: 7-12. ISSN 2313-0555.

[11] Drabek, P. Zalesak M. "*Effect of heat accumulation of buildings for control precision heating system*". WSEAS TRANSACTION

ON SYSTEMS AND CONTROL. Volume 11, 2016. Pp. 32-38. ISSN: 1991-8763.

[12] Mehling, H., Cabeza L.F. *Heat and cold storage with PCM An up to date introduction into basics and applications*. Auflage 2008. Heat and Mass Transfer . Springer. ISBN: 978 3 540 38556 2