An air-PCM heat exchanger for thermal storage in air-based solar thermal systems

Pavel Charvát[1], Lubomír Klimeš[2], Tomáš Mauder[3]

[1] Vysoké učení technické v Brně, Fakulta strojního inženýrství, Energetický ústav, Technická 2896/2, Brno, charvat@fme.vutbr.cz

[2] Vysoké učení technické v Brně, Fakulta strojního inženýrství, Energetický ústav, Technická 2896/2, Brno, yklime17@stud.fme.vutbr.cz

[3] Vysoké učení technické v Brně, Fakulta strojního inženýrství, Energetický ústav, Technická 2896/2, Brno, ymaude00@stud.fme.vutbr.cz

Abstract Phase change materials (PCMs) are materials with a high latent heat of melting. The PCMs can be used in various thermal storage applications and one of them is thermal storage in solar air systems. Air-based solar thermal systems are not as common as the water-based solar systems but they can be rather effectively employed for space heating and other purposes. A general problem with the solar thermal systems is the need for thermal storage in order to balance supply and demand of heat over a certain period of time. A numerical and experimental investigation of the performance of an air-PCM heat storage unit is described in this paper. The unit comprises of aluminum containers filled with paraffin-based PCM.

1 Introduction

A general problem of solar thermal systems is the need for thermal storage in order to balance supply and demand of heat over a certain period of time [1]. Water can easily be used as a heat storage medium in water-based solar systems but it is less practical for air-based systems. Building structures can also be employed as thermal storage mass but this arrangement is not suitable for all situations. The Tromb wall [2] is such an example of purpose-provided thermal storage in buildings. Another possibility is the use of rock beds where solid materials (usually pebbles) are used to store heat [3]. The commonly used heat storage arrangements like pebble beds or rock beds have a number of drawbacks (they use a lot of space, they are difficult to clean, the airflow distributions in the beds is usually non-uniform causing highly non-uniform temperature distribution in heat storage medium and thus decreasing energy efficiency of the system). A promising medium for thermal storage in these applications are phase change materials [4]. The phase change of a material provides rather high thermal storage capacity (and also energy storage density) in a narrow temperature interval around the melting point.

2 Heat storage unit

A heat storage unit that could provide a day-time-cycle thermal storage was considered in this investigation. The arrangement of the heat storage unit can be seen in **Fig. 1**. The aluminum containers filled with a PCM (Rubitherm CSM panels) were chosen for the test heat storage unit (air-PCM heat exchanger). This approach was adopted because the panels are quite easy to manipulate and the total thermal storage capacity of the unit can be increased by a higher number of containers. The containers have the dimensions of 450 mm x 300 mm x 10 mm and each of them can accommodate approximately 700 ml of PCM. The containers filled with Rubitherm RT42 were used. The RT42 has the melting range from 38 °C to 43 °C, heat storage capacity of 174 kJ/kg (temperature range 35 °C to 50°C) and the thermal conductivity of 0.2 W/(m·K). A unit comprising 100 CSM panels in 5 rows was used in the investigations. The test unit allows for testing of several operation modes.

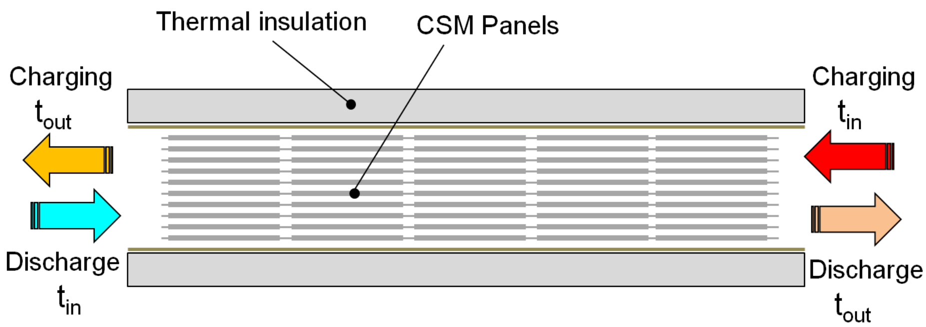

Fig. 1 Schematic view of the heat storage unit

In the situations when the unit is not fully charged it can make sense to reverse the air flow direction in the discharging mode (in comparison to charging mode – as indicated in **Fig. 1**) in order to increase the outlet air temperate and thus to increase the efficiency. Another issue is the position of the PCM panels in the unit. When the panels are positioned horizontally the PCM in the fully melted state will collect at the lower part of the container (CSM panel) and there will be an air gap between the PCM and the upper surface of the container. That gap can significantly influence heat transfer between the PCM and the air passing through the heat storage unit. The volume change between solid and liquid state is rather significant for many PCMs (it can be larger than 15 percent) and thus some empty space need to be kept in the containers to allow for that volume change.

3 Numerical model of the heat storage unit

The simulation tool TRNSYS 17 was used for the numerical investigations. The TRNSYS 17 is a 1D simulation tool that can be used for energy performance simulations of systems and buildings. The advantage of a 1D simulation model (in comparison to more complex 3D models) is very short computational time with regard to the simulated period (computational time of an annual simulation can be only a few seconds – in dependence on the complexity of the model). The price for the short computational time is the necessary simplification of the solved problem that needs to be done when implementing the model. The scheme of the numerical model of the heat storage unit is shown in **Fig. 2**.

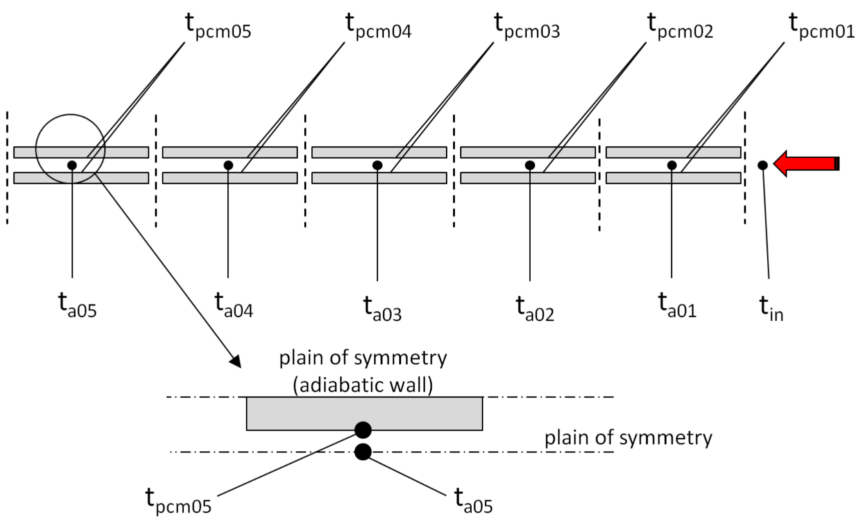

Fig. 2 Simplification of the storage unit for the numerical model

The simulations were carried out for the arrangement used in the experimental investigation (5 rows of the CSM panels with 20 panels in each row) but the model is not limited to this arrangement (the arrangement was chosen with regard to the test unit that is being built for experimental investigations).

3.1 Experimental investigations

An experimental set-up was put together in order to investigate the performance of the PCM-air heat exchanger experimentally. The set-up (shown in **Fig. 3**) consists of a PCM-air heat exchanger, electric air heater, fan and its control unit and the data acquisition equipment. The exchanger was thermally insulated with extruded polystyrene. A thermally insulated duct was used to lead the warm air outside of the room so as to reduce the heat load and thus maintain the constant room temperature.

Fig. 3 Experimental set-up

4 Results

Fig. 4 shows the comparison of experimental and numerical results (air temperature at the outlet of the heat storage unit). Air temperature at the inlet of the unit was constant in both charging and discharging period. The charging period lasted approximately 4 hours. The air temperature at the inlet was 58 °C in the charging period and 25 °C in the discharging period. The constant air flow rate of 230 m^3/hr was maintained in both charging and discharging period.

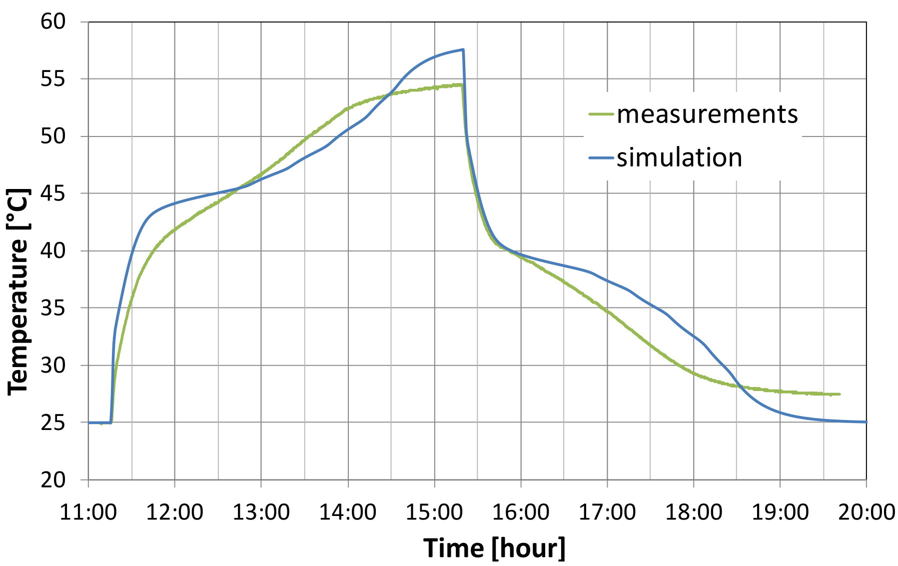

Fig. 4 Air temperature at the outlet of the thermal storage unit

5 Conclusion

A 1D simulation model of a heat storage unit for solar air systems, comprising aluminum containers filled with the PCMs, was developed. The model was implemented as a type in the TRNSYS 17 simulation tool. The type can be used together with other components like solar collectors, air-to-air heat pumps or other heat sources in air-based thermal systems. An experimental setup with a test heat storage unit was put together in order to validate the developed numerical model experimentally. The comparison of experimental and numerical results revealed certain discrepancies in predicted and measured temperatures and energies. The current version of the simulation model neglects heat loss to the surroundings what was one the reasons for discrepancy. Another reason is the uncertainty associated with the air flow inside the unit. Though the air flow between two parallel planes is a quite well investigated phenomenon in terms of heat transfer the uncertainty remains about the air velocities in particular air gaps between the panels in the heat storage unit. Melting of the PCM is yet another source of uncertainties. Proper simulation of melting and solidification requires a complex 3D numerical model that takes into account convection in the liquid PCM as well as the PCM volume change (to address voids during solidification). As so far, such models cannot be used to simulated long-term performance (e.g. seasonal performance) of the systems with PCMs because of the computational time.

Acknowledgement This work was supported by the Czech Ministry of Education under project OC10051 “Phase change materials for increased energy efficiency of air-based solar thermal systems in buildings”, the EU COST Action TU0802 ‘‘Next generation cost effective phase change materials for increased energy efficiency in renewable energy systems in buildings” and BUT project FSI-J-12-22 “Application of numerical modelling and optimization methods in engineering problems with state and structural changes”. The co-author, the holder of Brno PhD Talent Financial Aid sponsored by Brno City Municipality, also gratefully acknowledges for that financial support.

References

[1] PINEL, P., CRUICKSHANK, C. A.; BEAUSOLEIL-MORRISON, I.; WILLS, A. A review of available methods for seasonal storage of solar thermal energy in residential applications. In *Renewable and Sustainable Energy Reviews*, 2011, 15, 3341– 3359.

[2] JABER, S.; AJIB, S. Optimum design of Trombe wall system in Mediterranean region, In *Solar Energy,* 2011, 85, 1891–1898.

[3] ZHAO, D. L.; LI, Y., DAI, Y. J., WANG, R. Z. Optimal study of a solar air heating system with pebble bed energy storage. In *Energy Conversion and Management*, 2011, 52, 2392–2400.

[4] DUTIL, Y.; ROUSSE, D. R.; BEN SALAH, N.; LASSUE, S.; ZALEWSKI, L. A review on phase-change materials: Mathematical modeling and simulations. *Renewable and Sustainable Energy Reviews*, 2011, 15, 112–130.