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Thermal energy storage in ceresine-based accumulative heat exchanger

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Abstract

The paper contains description of conception, realization a tests of an accumulative heat exchanger. The appliance has a sectional construction with four cassettes filled with ceresine – a mixture of paraffins. The exchanger is dedicated for ventilation and cooling applications, especially in passive buildings. Usage of phase change materials is one of the most important topics in the whole area of energy storage. Series of tests have been done, during which both, the casing and the cover have been insulated, thereby thermal losses have been limited. Furthermore, paper presents an influence of insulation on the heat storage possibility in the proposed accumulative heat exchanger.

Keywords: Energy storage; PCM; Accumulative heat exchanger

Nomenclature

PCM	–	phase change materials
T	–	temperature, °C
$\dot{V}$	–	volume flow rate, m^3/s
k	–	coefficient of thermal conductivity, W/m K

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1 Introduction

Lack of coverage of energy demand and supply is one of the most important issues in the modern power technology. It is particularly essential in relation to use of renewable energy sources (RES), both in electrical grids and household applications. In prosumer cases, usage of RES allows independent production of domestic hot water, heating and electricity generation. Produced energy can be easily sold and been available in the grid. Also, the difference between energy demanded during the night and energy supply during the day is a significant problem for ventilation and cooling systems designers. A solution of these problems can be based on energy storage devices, such as heat storage tanks. Newly developed methods of heat storage focus inter alia, on usage of phase change materials (PCM) [1]. Latent heat reaches definitely higher values than sensible heat for a lot of substances. It provides better values of energy density regarding to the volume or mass, which is the main parameter in the area of energy storage. A wide range of PCM have been investigated and analyzed for heat storage possibilities [2].

PCM based heat exchangers dedicated for an air conditioning and ventilation systems have been constructed and analyzed [3,4]. This type of solution uses both, sensible and latent heat of PCM in energy storage. Labat *et al.* [3] proposed heat exchanger containing more than 27 kg of PCM, which has been presented and tested. Device was designed to store enough energy to replace a 1 kW heat pump during 2 hours operating time. Dolado *et al.* analyzed the thermal performance of a PCM-air heat exchanger based on paraffins [4]. The main goal in constructing of such devices is to select proper material with melting temperature (in case of solid-liquid PCM) corresponding to the expected temperature of heat source. Moreover, dimensions of the device are important and there is a necessity to minimize them. In this paper, construction and tests of accumulative heat exchanger based on ceresine are presented. Ceresine is a mixture of paraffins with the melting temperature in the range of 61–78 °C. Also, the influence of insulation on constructed device performance was investigated. Measurements were done with the air volume flow rate in the range of 0.03–0.05 m^3/s, so it can be assumed that the insulation was the only variable.

2 Experimental stand

The experimental stand (Fig.1) has been prepared by modification of an existing stand used for heat exchanger and fans analyzes [5]. The system contains: electric air heater, thermocouples for temperature measuring (inlet and outlet), flowmeter and radial fan providing airflow, all placed in order to air flow direction. The whole system is connected with 0.2 m steel duct. Air temperatures are measured at three points (Fig. 1) in the center of the duct. Volume flow rate is calculated from the area averaged dynamic pressure component over the cross-section (Flowmeter, Fig. 1).

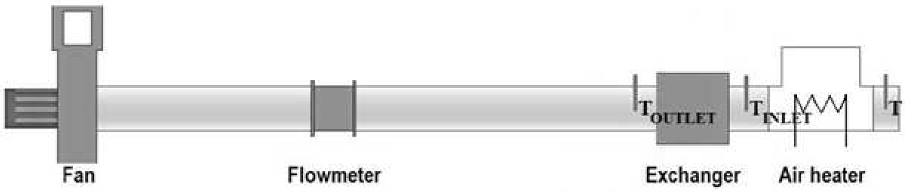

Figure 1: Experimental stand.

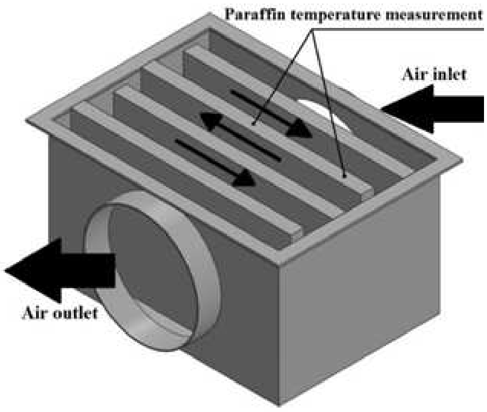

Figure 2: The general look of accumulative heat exchanger, with airflow direction indicated and thermocouples locations.

The 2 kW electric air heater sets up the temperature and relative humidity of supplied air. Accumulative heat exchanger construction is presented in Fig. 2. Cassettes contain ceresine, of approximately 1.25 kg each. Thermocouple placed at the outlet of the exchanger is used to measure the temperature of air stream leaving the exchanger. It allows to assess the amount of energy accumulated in PCM. Additional two thermocouples in the second cassette allow to measure and calculate mean paraffin temperature. The average volume flow rate in the system is controlled by a radial fan driven by an inverter. The accuracy of used measuring devices is presented in Tab. 1.

Table 1: The accuracy of measuring devices.

Device name	Measured magnitude	Measurement ranges	Margin of error	Device output signal type
HalstrupWalher P26	Differential pressure (dynamic component)	10/50/100/250/500 Pa	± 0.5% of measuring range, min. 0.3 Pa	Voltage 0–10 V
DeltaOhm HD48T	Relative humidity	0–100%	± 2% (for range of 10-90%) ± 2.5% (remaining range)	Current 0–25 mA R = 234 Ω
	Temperature	(-20)–(+80) °C (NTC 10 kΩ)	± 0.3 °C for range of 0–70 °C) ± 0.4 °C (remaining range)	Current 0–20 mA R = 237.5 Ω

Calculated propagation of uncertainty provides:
temperature, T, measurement uncertainty: $u(T) = 5\%$
differential pressure, p_d, uncertainty: $u(p_d) = 0.5\%$.

3 Results

The exchanger was examined in three cases. In the first case the exchanger was not insulated at all. Then everything except the cover was insulated. And finally the whole construction was insulated (Fig.3). The insulation was made from mineral wool ($k = 0.041$ W/m K). The influence of insulation on the heat losses and device operation has been determined. Figures present inlet and outlet air temperatures and averaged ceresine temperature in the second cassette. Air temperatures at inlet and outlet determine capabilities of usage of such a devices. All figures are divided into two main parts:

charging and discharging. The first one means stage of heat accumulation in the exchanger caused by air heater work. Discharging is the heat releasing from the device to installation with keeping constant air volume flow rate and without heat supply from air heater.

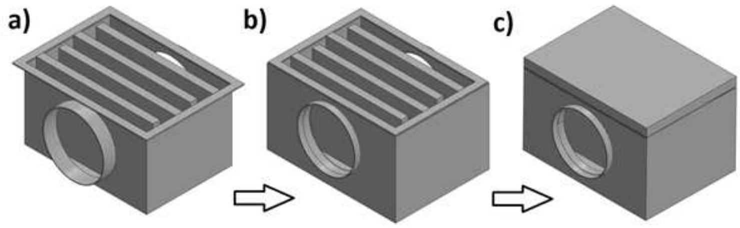

Figure 3: The heat exchanger insulation process stages: a) uninsulated exchanger, b) insulated casing, c) fully insulated unit.

It can be assumed that the inlet and outlet temperatures reached plateau during the charging stage. Air inlet temperature was maintained in the range of 60–80 °C. Although paraffin has not been fully melted. In the cases with air volume flow rate nearest to 0.035 m^3/s, measurement time was appointed by outlet temperature reaching 50 °C. Figure 4 presents temperature profiles in the uninsulated exchanger. The inlet temperature fluctuations were caused by overheating protection device in air heater. Paraffin maximum temperature in second cassette was close to the outlet air temperature. That was caused by the biggest thermal losses through steel casing. Next, the measurements were performed by using autotransformer as a temperature controller, instead of heater protecting device. As a result of this modification, temperature fluctuations became much smaller.

Heat losses limitation made by insulating an exchanger casing decreased temperature disturbances (Figs. 5–6). Additional heat resistance provided by mineral wool has limited heat losses through casing and resulted in higher inlet temperature. It was the outcome of better accumulation efficiency (compare Figs. 4 and 5).

Final modification brought the full insulation of the exchanger (Figs. 7–8). The top cover made from plexiglas was also coated with wool, which limited the heat losses by thermal radiation. Paraffin temperatures were higher than in the previous case. Discharging stage lasted longer than on the case of uninsulated exchanger, providing longer heat supply. Charging period was reduced by half in fully insulated construction compared to uninsulated one.

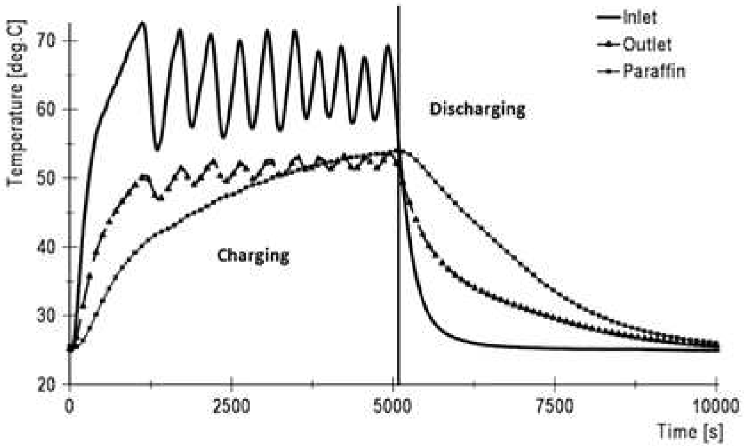

Figure 4: Air and paraffin temperatures in the uninsulated accumulative heat exchanger, volume flow rate $\dot{V} = 0.03$ m^3/s.

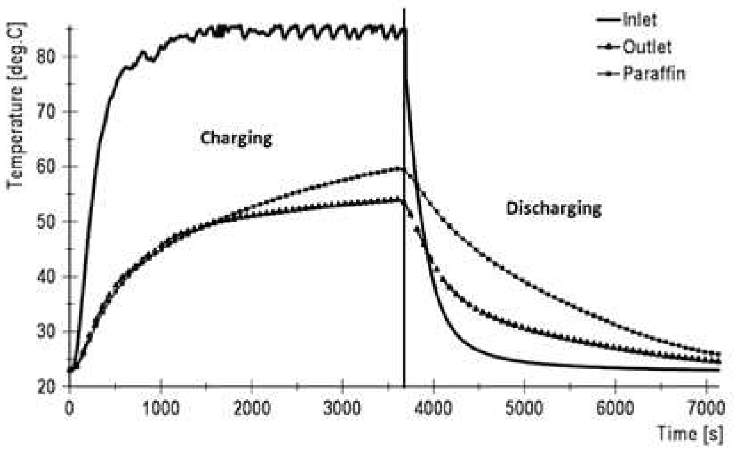

Figure 5: Air and paraffin temperatures in the accumulative heat exchanger – insulated casing, uninsulated cover, volume flow rate $\dot{V} = 0.04$ m^3/s.

Paraffin temperature in the uninsulated case hardly reached outlet air temperature after 1 h. Casing insulation causes definitely faster increase of the paraffin temperature and equalization with air outlet temperature after 0.1 h. Proper insulation provides correct operation of the device and allows to quickly respond to the temperature fluctuations.

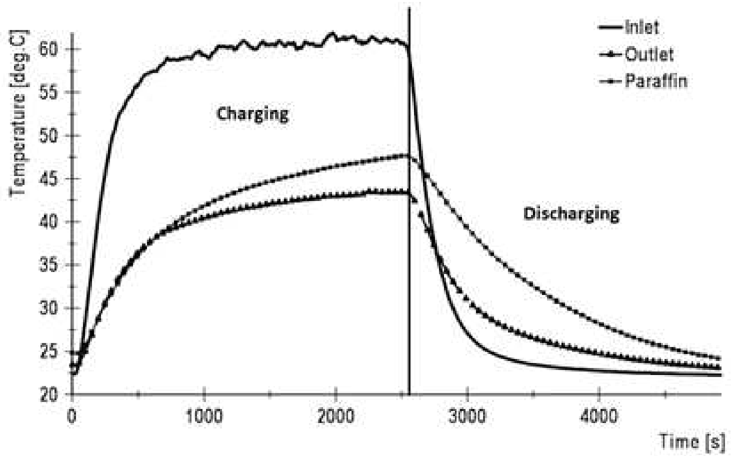

Figure 6: Air and paraffin temperatures in the accumulative heat exchanger - insulated casing, uninsulated cover, volume flow rate $\dot{V} = 0.05$ m^3/s.

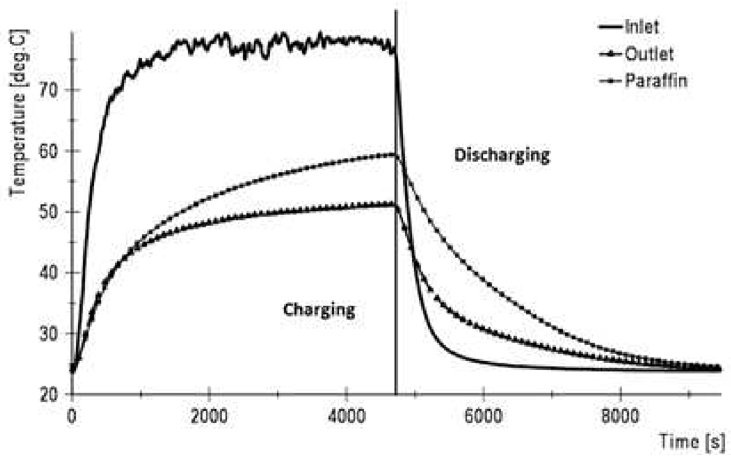

Figure 7: Air and paraffin temperatures in fully insulated accumulative heat exchanger, volume flow rate $\dot{V} = 0.038$ m^3/s.

4 Conclusions

An accumulative heat exchanger is a complex unit, which can be used to store an additional or waste energy. Heat accumulation efficiency and effective heat removal are the crucial aspects in the case of large scale applications. Heat losses limitation is one of the most important research topic

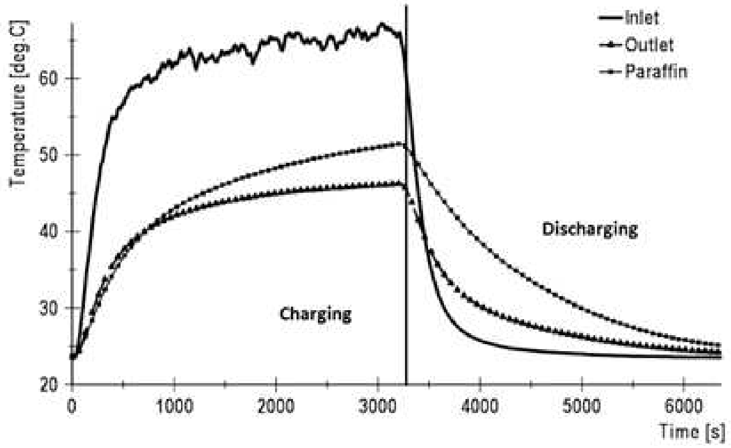

Figure 8: Air and paraffin temperatures in fully insulated accumulative heat exchanger, volume flow rate $\dot{V} = 0.048$ m^3/s.

in the heat exchange field. Nowadays, considered accumulative heat exchanger is a prototypical device and much more investigations must be done to improve temperature distribution, heat transfer mechanism and make the smaller construction, which will allow to apply it on a wider scale. Insulation made from mineral wool, which is a widely available building material, has significantly limited the heat losses and made the temperature distribution more stable. Further research should aim to limit pressure losses in heat exchanger and to intensify heat transfer from air to ceresin.

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