PCM - 17

Utilization of Phase Stabilized PCM-Compounds in Home Appliances

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SUMMARY

PCM-compounds were applied to stabilize the temperature of special storage compartments particularly during defrosting periods in a refrigerator. The stabilizing effect was measureable but not very significant. The same statement holds for the application of PCM-compounds to reduce the condensing temperature of the refrigeration cycle of an already high energy efficient fridge. However, experiments showed that remarkably energy savings can be achieved by the application of the PCM in a laundry dryer. The basic idea of this promising application is to place PCM elements in the stream of moist air and to store and afterwards reuse the heat of condensation.

INTRODUCTION

PCM-compounds are a new class of thermal storage materials**.** Some examples can be found in literature (San 2004, Alkan and Sari 2008, Komiyama et al. 2012). They are a combination of conventional organic PCMs with supporting polymeric structures. Their outstanding property is the shape stability even in the molten state. PCM-compounds can be applied as sheets, foils, granules or even coatings in direct contact with thermally active components or heat transfer fluids. This shape stability without further encapsulation facilitates new applications for thermal storage materials, not only for niche applications but also for series products like home appliances. In 2013 a joint project of three German partners (Thuringian Institute of Textile and Plastic Research [TITK] for material development, ILK Dresden for system integration and component testing and BSH Hausgeräte GmbH for application development) was started to evaluate the potential of PCM-compounds in home appliances. The paper is presenting ideas and first results of this ongoing project.

METHODS

The TITK developed a production process for the PCM-compounds (Reinemann et al. 2013). The compound consists of a matrix of amorphous block copolymers with integrated paraffin as phase change material. The paraffin is retained in the matrix by physical bonding. PCM-compounds with melting temperatures between -4 °C and 80 °C can be manufactured as sheets by means of a co-rotating twin-screw extruder. The PCM-compounds are rigid and opaque at temperatures below melting temperature and rubber-like and translucent when the paraffin is molten in the matrix. The compounds have a mass density of about 0.9 g/cm³ below melting temperature and a storage capacity of up to 180 J/g. It is possible to fill the

PCM-compounds with metal or graphite particles to increase the thermal conductivity. The material can be laminated with foils. Figure 1 shows as an example the measured apparent heat capacity for the heating and cooling of a so called OC27.

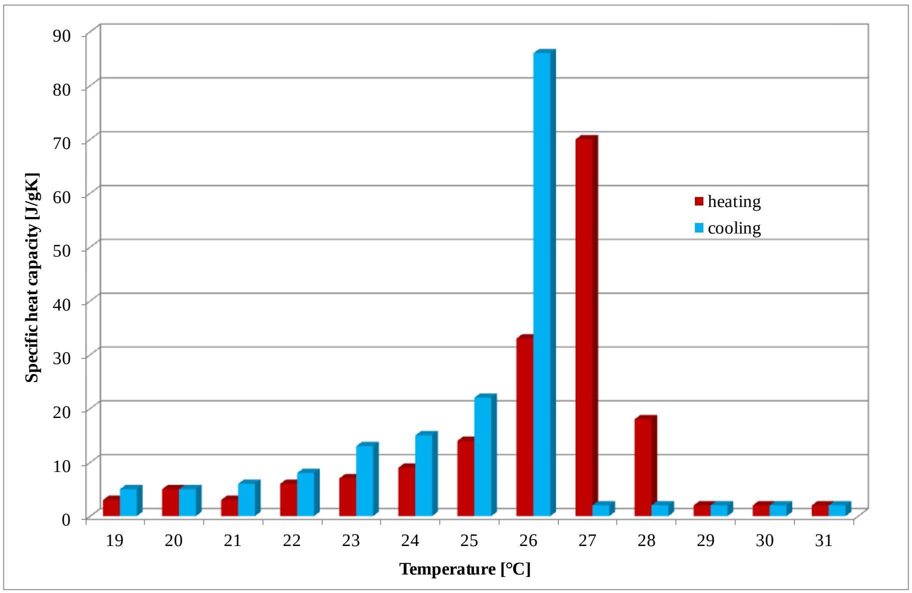

Figure 1: Temperature dependent apparent heat capacity of the PCM-compound OC27

With that technology TITK is able to produce tailor made thermal storage materials and components according to the requirements for the application in particular home appliances. The following paragraph describes mainly experimental results of the PCM-compound integration into refrigerators and laundry dryers.

RESULTS and DISCUSSION

Temperature stabilization in storage compartments with tightened temperature requirements in household refrigerators

Modern refrigerators are equipped with storage compartments for goods with special temperature requirements. One example is the refrigerator KSF36 manufactured by the project partner BSH. It comprises a so called vitaFresh compartment containing three drawers to store goods at temperatures close to 0 °C. This type of no-frost refrigerator comprises a finned evaporator which has to be defrosted from time to time. During defrosting there is a risk that the temperature inside the vitaFresh drawers exceeds the permitted level. It was the idea to use sheets of PCM-compounds to stabilize the temperature of the vitaFresh drawers during that critical period. Figure 2 shows a section of the base portion of the KSF36 where the vitaFresh compartment is located.

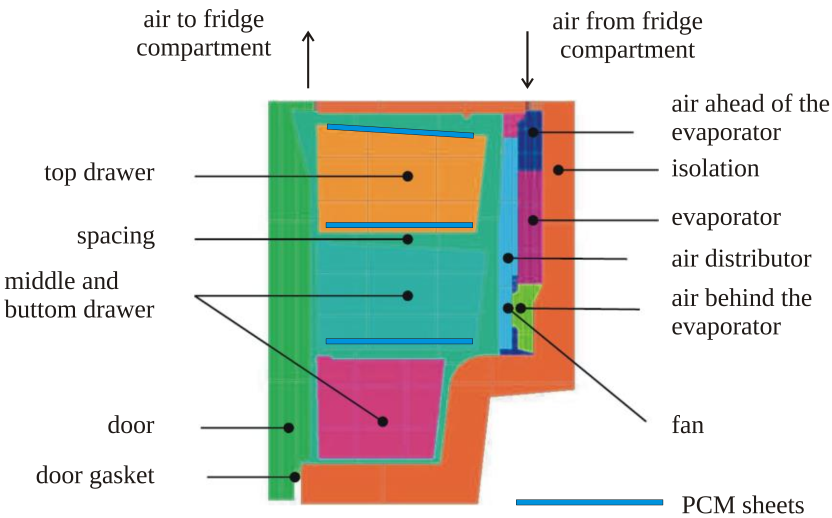

Figure 2: Section of a KSF 36 with three vitaFresh drawers

The dark blue bars mark the positions where PCM-compound sheets were integrated. They were attached at the lid and at the bottom of the top drawer and at the bottom of the middle drawer (the middle and the bottom drawer don't have a lid). A total of 512 g of a PCM-compound with a phase change temperature of 2 ℃ was attached to the drawers. Figure 3 shows the results of temperature measurements which were carried out at BSH according to the standard DIN EN ISO 15502. Light colored lines indicate temperature measuring results of test packages inside the vitaFresh drawers of the series refrigerator and dark colored lines show the respective temperature trends with PCM integration. Simultaneously, a CFD model was developed at ILK Dresden using the software ANSYS Fluent 14.5. The simulation model used measured temperature trends of the "air behind the evaporator" (see Figure 2) as input parameters. The purpose of the simulation model was to get a better understanding of the measured temperature trends. Figure 4 shows simulation results which were achieved for the boundary conditions as they were applied for the experiments.

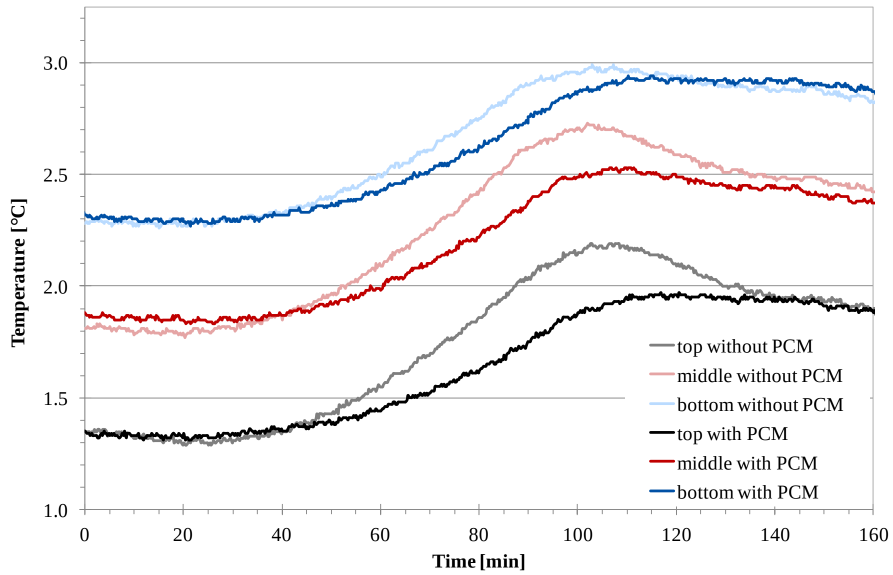

Figure 3: Results of temperature measurements of test packages in vitaFresh compartment with and without PCM

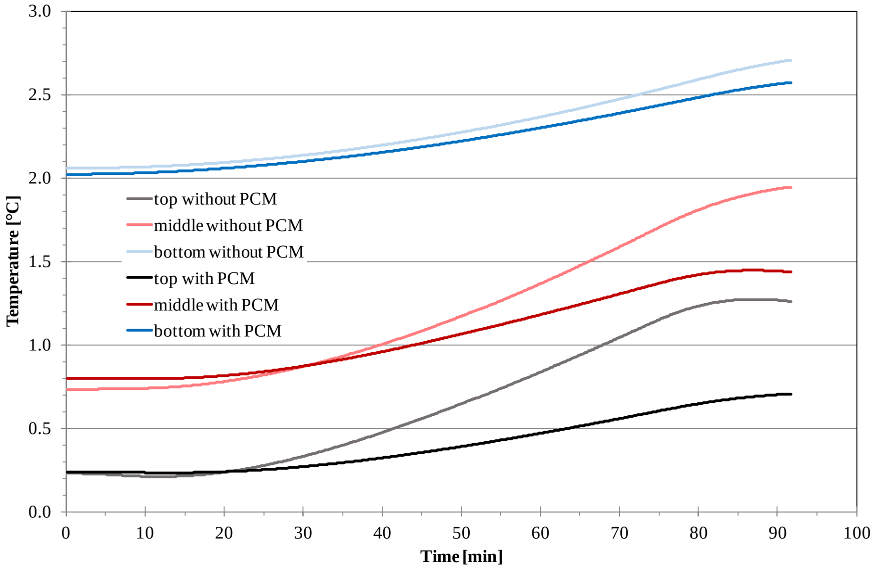

Figure 4: Result of CFD simulations for the temperature trend of test packages in the various vitaFresh compartment with and without PCM

Comparing Figures 3 and 4 the following conclusions can be drawn: calculations and measurements are in good coincidence. The effect of the application of PCM sheets is mostly pronounced in the top drawer (black and gray lines in Figures 3 and 4). The maximum temperature during the defrost period could be reduced from 2.2 °C to 2.0 °C in the experiment (ΔT_{meas} = -0.2 K). The calculations overestimate this reduction with a simulation result of ΔT_{calc} = -0.6 K. The effect of the PCM integration on the maximum bottom drawer temperature (light and dark blue lines in Figures 3 and 4) is very small for both kinds of investigations, measurement and simulation.
Comparing the small temperature balancing effect of the PCM application for a vitaFresh compartment with the economic effort for a technical integration of the thermal storage material into the compartments a series introduction appears not very likely.

PCM-compounds to increase the thermal mass of the condenser of refrigerators
In general refrigerators work as heat pumps which generate the cold by transmitting heat from the cooling compartment to an external component where the heat is rejected to the environment. In refrigerators with a mechanical compression system this component is the so called condenser. The (electrical) efficiency of a compression cooling system is as better as lower the temperature difference between cold side (this temperature is quite fix due to the temperature requirements of the cooling compartment) and the warm side (condenser) of the circuit can be maintained. Because the refrigeration cycle of most refrigerators operates in on/off-mode it is advantageous to give the condenser a high thermal mass to achieve the target of low condensing temperatures during compression cycle operation. Some refrigerators' condenser is equipped with bitumen for that purpose. Experiments were carried out to test and compare the performance of the PCM-compound by contrast to the established bitumen.
For this investigations temperature and energy consumption measurements were carried out at a small Built-in upright-freezer of the manufacturer BSH. Results of the temperature measurements for two on/off-cycles are given in Figure 5.

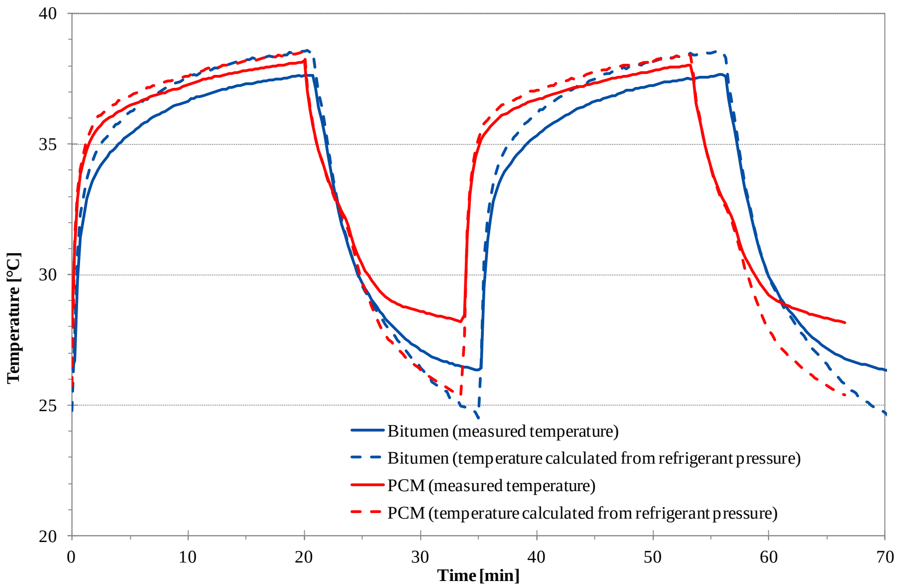

Figure 5: Temperature measurements at the condenser of a refrigerator with bitumen and with PCM-compound

Temperature measurements with temperature sensors are marked with continuous lines in Figure 5. These are more or less local measurements. The dashed lines represent temperature values calculated from pressure measurements and the vapor-pressure curve of the refrigerant. These temperature values give more an inside view of the refrigeration cycle: in on-mode (high temperatures) this value gives a good average of the temperature of the condenser tube, in off-mode it represents the temperature of the coldest section of the high pressure side of the refrigeration cycle.
For the PCM-measurements the condenser was equipped with 333 g of the PCM-compound OC33.1.1.10 (melting temperature 33 °C) filled with graphite to improve the heat conductivity. The mass of the bitumen for the reference measurements was 2950 g.
Comparing the blue and the red curve the following facts are significant: temperature differences between both versions are small in general. Comparing the dashed lines (these values are responsible for the energy consumption) it has to be stated that temperatures with PCM-compound rise somewhat faster after compressor start than the condenser temperatures with bitumen. In off-phases the local temperature measurements show that the PCM-compound cools down slower than the bitumen. In general it was the result of the temperature measurements that no significant energy consumption reductions were expected.

This was verified by energy consumption measurements which were extended by variations of the refrigerant charge for both condenser versions. Figure 6 shows the results of these investigations.

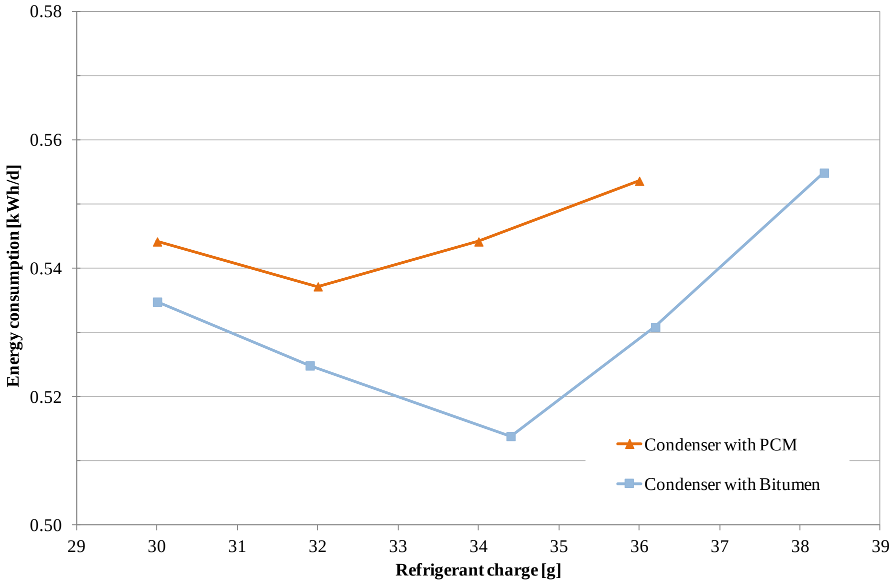

Figure 6: Energy consumption of a refrigerator with bitumen or PCM-compound attached at the condenser in dependence on the refrigerant charge

Both curves show a pronounced minimum of the energy consumption for different refrigerant charges. This underlines the importance of refrigerant charge variation investigations when the refrigeration circuit is modified in any way.

As expected from the temperature measurements no reduction of the energy consumption was achieved by substituting the bitumen by the PCM-compound. A minimum energy consumption of 0.537 kWh/d (at 32 g refrigerant charge) for the PCM-version is faced an energy consumption of 0.514 kWh/d (at 34.4 g refrigerant charge) for the refrigerator with bitumen. This is an increase of about 4 %. Due to these experimental results no further investigations were carried out regarding the substitution of bitumen by PCM-compounds at condensers of refrigerators. There are two recent investigations known from literature which found an energy saving potential by attaching PCM to the condenser of a refrigerator (Cheng et al. 2011 and Sonnenrein et al. 2015). But these comparisons didn’t use a bitumen condenser as reference as it was the case for the investigations presented here.

Application of PCM-compounds in laundry dryers

There are laundry dryers with different working principles available on the market. The following paragraph refers to experimental results which were achieved at a condenser dryer with cooling by ambient air. The working principle of such a condenser dryer is schematically shown in Figure 7a. The so called process air is heated by an electrical heater. A fan (not shown in Figure 7) feeds the hot air into the laundry drum where it absorbs moisture. The laundry is dried by that process. Behind the drum the hot and humid air enters a cross-flow heat exchanger. This heat exchanger is cooled by ambient air and when the process air passes this component water is removed in liquid form from the process by condensation. Leaving the heat exchanger the partly dehumidified process air flows again to fan and heater and the circuit is closed. The electrical energy which is required by the dryer is mostly used to evaporate the water from the laundry. The provided heat of evaporation is transferred to the cooling air in the cross-flow heat exchanger and is lost to the environment in that way.

It is the idea to reuse a part of that heat of evaporation by placing a PCM-compound storage in the process air in between heat exchanger and heater (see Figure 7b).

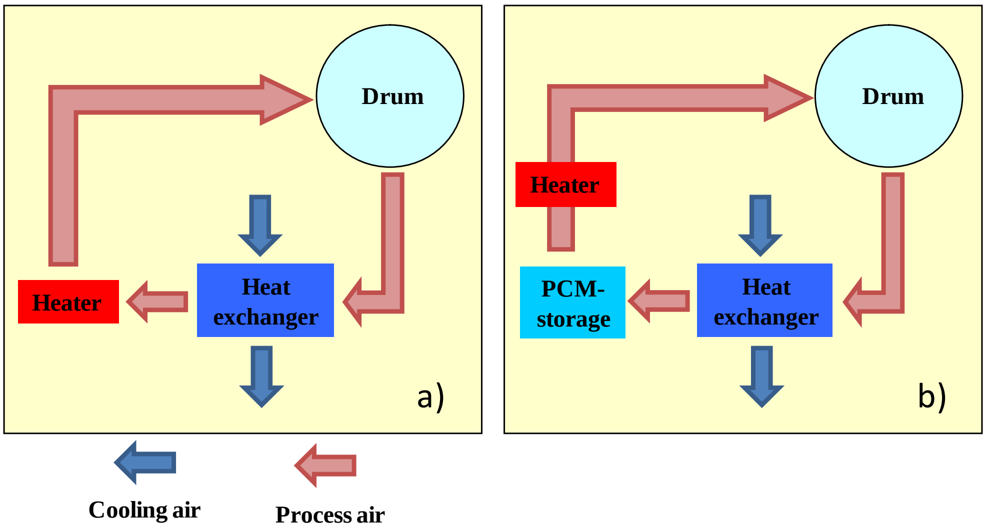

Figure 7: Operation principle of an air cooled laundry dryer without modifications (a) and with PCM storage integration (b)

During a first drying phase (with active heater) the process air which leaves the heat exchanger (with nearly 100 % relative humidity) passes through the cold PCM storage. In the storage the dehumidification process continues but the accumulated heat of condensation is not wasted to the environment but stored in the PCM. In a second drying phase the heater is switched-off and the PCM storage takes the task of the heater. In that way the drying process can be continued and finished without further electrical heating.
To verify this idea a laundry dryer of the type T20 was modified by integration of 1950 g of the PCM-compound OC80. An example of various trends measured with the modified dryer is given in Figure 8.

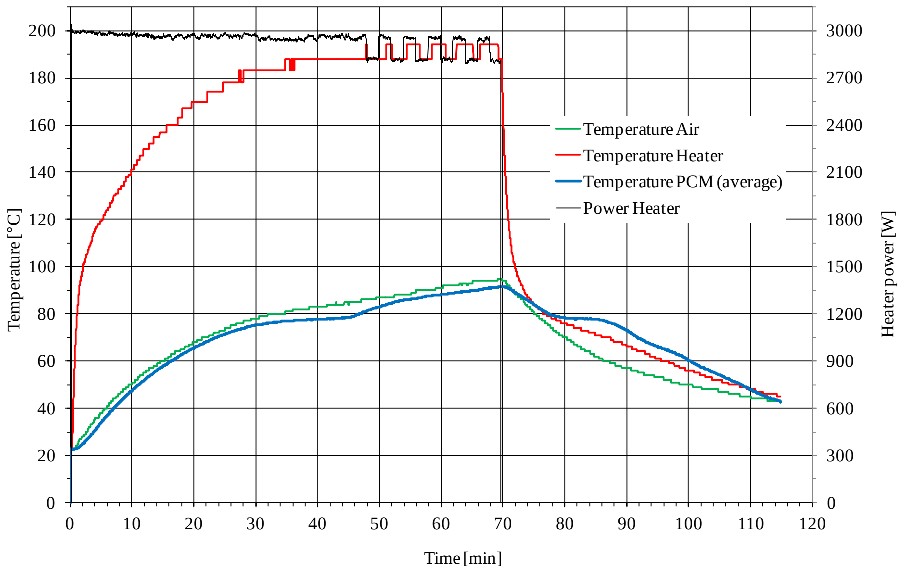

Figure 8: Temperatures and heater power of a drying process with PCM storage

The black line represents the heater power and the red line the heater temperature. 70 minutes after the start of the drying process the heater was switched-off. The blue line shows the average of different temperature sensors in the PCM-storage and the green line represents the temperature of the process air. After process start the process air temperature follows very slowly the heater temperature due to the high thermal mass of the wet laundry. About 45

minutes after process start the slope of the PCM temperature changes significantly. This is an indication that the PCM has exceeded its melting temperature and the PCM storage is “charged”. After switching-off of the heater the PCM temperature returns to the melting temperature within about 8 minutes and shows the well known “PCM plateau” for about 10 minutes. The temperature of the process air was kept above 50 °C for half an hour after switching-off of the heater.
Experiments with the PCM laundry dryer are still in progress. Air flow conditions will be revised, process parameters adjusted, long term stability tests performed and the storage materials improved. It is expected that energy savings of about 8 % can be achieved with the integration of the PCM storage into the laundry dryer.

CONCLUSIONS

On one hand polymeric PCM compounds offer numerous new application possibilities due to their freedom of shaping and the elimination of encapsulation. On the other hand energy efficiency has been a development target for home appliances for many years. Therefore many home appliances already have a high standard regarding energy consumption. This is the reason why further efficiency improvements by PCM integration are not a “fast-selling item” despite of the outstanding properties of the PCM-compounds. The thermal processes in home appliances have to be analyzed carefully and the PCM storages must be designed according to these findings. Last but not least advantageous technical solutions must prove to be economically viable.

ACKNOWLEDGEMENT

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