CHARGING OF A THERMAL BATTERY COMPOSED OF OPEN-CELL METAL FOAM AND PHASE CHANGE MATERIAL FOR USE IN PHARMACEUTICALS TRANSPORT

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ABSTRACT

Active coolers for pharmaceutical transport require maintenance significantly and present risks with movable parts. Passive coolers on the other hand have less components and do not require chilling units on board unlike their active counterparts. Phase change materials (PCM) have already been used in pharmaceutical logistics for the constant temperature provided thanks to the latent heat released during melting. However, before docking the gel packs require a significant amount of time for freezing due to their low thermal conductivities. In this study, the overall thermal conductivity of the enclosures of PCMs in a thermal battery is increased via combining them with open-cell metal foams. Experimental results on the thermal battery prototype show that the attempts for quickening the freezing process are promising for further research.

INTRODUCTION

Today active and passive shipping containers are available on the market. The active containers have a compressor unit on board generating the required heat withdrawal. The compressor can be driven by an engine or by an electrical battery. The system is heavy and the moving parts require considerable need for maintenance. Moreover, engines or electrical batteries are not preferred in air freight cargo. As the containers are also suffering shocks and vibrations during transport, refrigerant leakage is a major problem. Leakage may be 20%/year (up to 40%/year). Consequently, there is a strong drive towards passive solutions, which do not have moving parts on board.

During the transport of pharmaceuticals, the cold chain needs to be maintained. This means a predetermined temperature range should be respected. The range between 2 and 8 °C, often described as “chilled”, is the most used. For example, any vaccine can be transported in this temperature range as reported in the guide by World Health Organization [1].

To improve the performance of passive containers, Phase Changing Materials (PCMs) are used. A PCM is a heat storage material with a high heat of fusion, that utilises the processes of phase change between solid and liquid (melting and congealing) to store and release large quantities of thermal energy at constant temperature, namely the latent heat.

Research by Oró et al. [2] is a first example of the possible uses of PCM in cooling applications. Observed was the capability of a passive, insulated container to have an inside temperature below 0 °C with and without PCM. The PCM occupied 3,36 % of the internal volume of 270 liters and was pre-cooled for 24 hours at -22 °C. For the container, a commercial freezer was used with 5 cm polyurethane insulation on all walls, except the double glass door. The aforementioned volume of PCM was selected so that the freezer could remain below 0 °C for 10 hours being warmed up by ambient temperatures, while an empty box lasted only 3 hours. When the same freezer was filled with 42 kg of dummy loads, simulating frozen food, the time improved from 12 to 22 hours. Around 8 kg of PCM thus nearly doubled the lifetime of 42 kg of frozen food in case of power failure for this freezer.

A study about clinical trial transport [3] involved the simulation of a transit between 2 hospitals using passive containers. The temperature was measured during the transit and they were able to successfully transport dummy medication remaining in a temperature range of 2 to 8 °C in different seasons, represented by days with the mean temperature. The gel packs of 21 cm on 15 cm on 3 cm, containing a non-specified PCM, weighed around 680 grams each. The pre-cooling of them took 24 hours. With only 3 or 4 small frozen gel packs they were able to maintain the temperatures for at least 48 hours in a compact shipper with a 25-liter internal volume. The shipper had 6.5cm thick polystyrene around as insulation.

Although the use of PCMs in passive containers is widespread, it has its disadvantages too. The ad-hoc use of PCMs require refrigeration for a considerable period of time until they are fully frozen, therefore transporters need to have a large stock of them that is cooled constantly, which can cause logistic problems. All that is caused by the major disadvantage of PCM: low thermal conductivity.

In this study, PCM was combined with open-cell aluminum foam in a metal container to improve the overall thermal conductivity. An open-cell foam has voids connected via open pores, and this way it can be impregnated with PCM [4]. The metal foam, with a high porosity, is aimed to conduct heat in the composite, while the PCM withdraws the heat especially during melting, also keeping the interiors of a passive container at a constant temperature.

EXPERIMENTAL SETUP

The experimental setup is as roughly depicted in Figure 1. The cooling unit at the center of this study, which can also be called the thermal battery was designed so as to be charged at a central location before transport. Therefore a chilling unit was also included in the experimental setup. This unit was custom built by Frigro and had a large reservoir for the cooling liquid, Temper T-40, with a freezing temperature of -30°C. The chilling unit was also included a Krohne Optimass 1400 Coriolis flowmeter for the cooling stream and temperature measurement points at the outlet and the return points. The mass flow rate accuracy was lower than 0.2% of the measured flow rate. Before any test, the unit was run for a few hours to decrease the temperature of the entire cooling liquid in the reservoir down to -15°C.

The cooling unit had separate channels for PCM-metal foam combination and the cooling liquid. The channels for the cooling liquid could be considered open because when the chilling unit was on, the liquid was able to travel through the only inlet and outlet of the thermal battery and find its way back to the chilling unit where it was further cooled down. In the closed channels of the thermal battery on the other hand were the metal foam pieces impregnated with PCM. The metal foam pieces were produced by Alhedron and they all had a porosity of 0.93. The PCM model was RT5HC of Rubitherm. Its melting temperature range was listed as 5-6°C. It had a heat storage capacity of 240 kJ/kg and its thermal conductivity was only 0.2 W/mK.

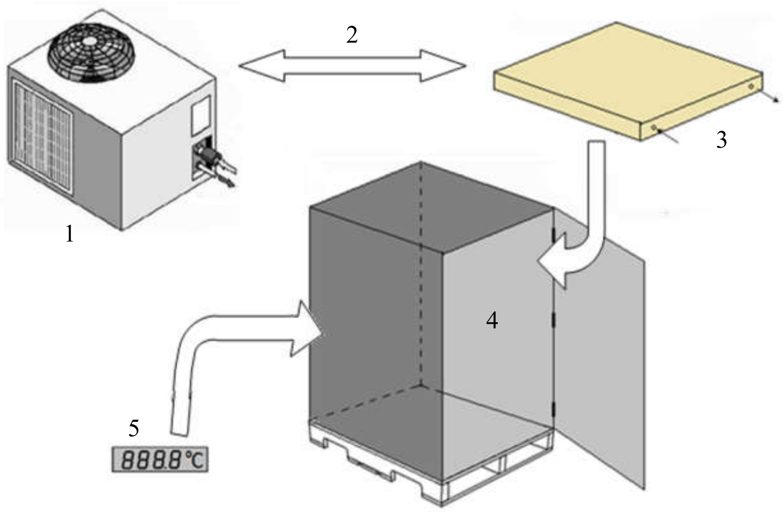

Figure 1. Experimental setup for the passive cooling prototype: 1. Chilling unit, 2. Insulating hoses, 3. Cooling unit, 4. Passive cooler, 5. Data acquisition

The passive cooler which housed the thermal battery had an internal volume of 486 liters. The 80-mm-thick walls were made of polyurethane to provide insulation and to maintain a high thermal gradient with respect to the ambient. The weakest points in this sense were the door which had a thickness of 50 mm and the elastic band around the door to isolate the box physically. Therefore additional insulation was provided by attaching swellband next to the elastic band. The door also had a handle and a lock in order to keep the interiors of the box unaffected any kind of perturbations. The overall heat transfer coefficient multiplied by the heat transfer area *UA* of the passive cooler was also determined by placing a 1-kW heater inside and measuring the inner temperatures applying electrical resistance analogy, taking into account only the conduction resistance of the box wall. *UA* was found as 2.62 W/K although with a high uncertainty of 0.5 W/K. The measurement devices will be changed and a more accurate finding will be filed.

Type T thermocouples were used to acquire temperature data. To make the temperature measurements more accurate than the listed accuracies from manufacture, thermocouples were calibrated in batches using a Druck calibration furnace with model DBC150 and an associated referential probe PT100. As a result, highest error was found as 0.071°C. All of the thermocouples were connected to a Keithley 2700 data logger which was controlled by a sımple Labview program installed on a PC.

For a given run, chiller had already cooled the cooling fluid to -15°C and it was connected to the two ends of the thermal battery via non-spill couplings and highly insulated hoses. To start charging the thermal battery, pump was started and T-40, the cooling liquid was sent into the thermal battery. The T-40 temperatures at the beginning were acquired as values higher than -15°C because of a certain amount of liquid remaining in the hoses were exposed to ambient rather than being chilled like the rest in the reservoir. This problem will be solved shortly by using additional connections to create a short circuit. After 10 minutes, the temperature outlet and inlet liquid temperatures were observed to be the same and heat from the thermal battery was assumed to be transferred so that the PCM was solidified. In addition to the temperatures from the cooling liquid, outer-wall temperatures were acquired from points at the inlet and the outlet of the cooling unit inside the passive cooler.

RESULTS

The cold chain of pharmaceuticals have been involving the use of cold packs which require a long time. 45 minutes has been necessary for chilling to completely freeze the PCM. However, in this case, the thermal battery is already inside the passive cooler where it is cooled to complete phase change in 17 minutes, Figure 2. The process is facilitated by the enhanced effective thermal conductivity.

The wall temperature measurements on the outer surface of the thermal battery fails to deliver viable input because of the effects from ambient. Therefore new solutions have to be sought to get insight into the thermal behavior inside the PCM channels. In Figure 2, one can see the relaxation of the wall temperatures onto each other is observed very late compared to that between the chiller fluid temperatures from two ends.

After the charging was complete, The thermal battery was disconnected from the chilling unit. A vertical pole on which 3 thermocouple tips were equidistantly spaced was put inside the passive cooler box and the door was closed. Afterwards, temperature data was acquired for 3 days to monitor the thermal behavior of the passive cooler when the PCM was absorbing heat, behaving accordingly in both latent heat and sensible heat regions. Figure 3 shows the averaged temperature inside the passive cooler in addition the wall temperature of the thermal battery. It can be seen that during melting, the interior temperature exceeds 8°C due to heat loss through the walls of the passive cooler. This is also a sign of inadequacy of only one thermal battery.

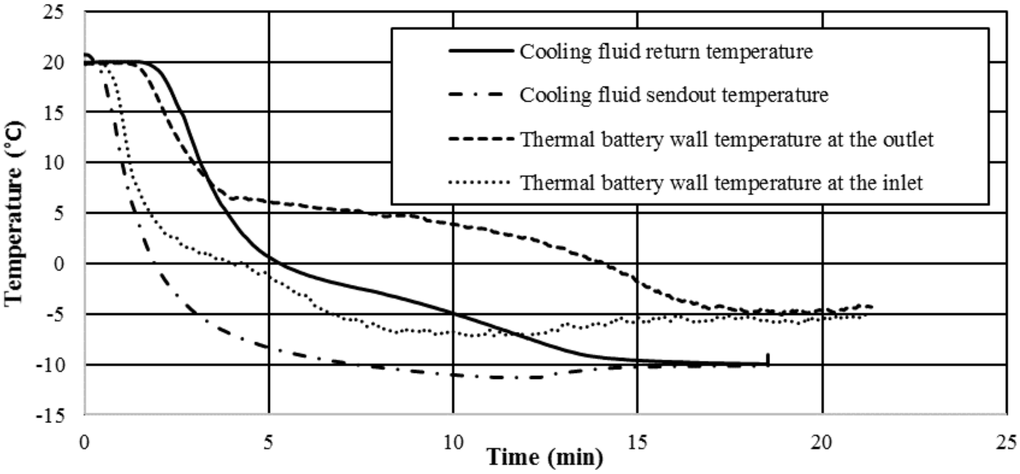

Figure 2. Temperature changes during charging the thermal battery

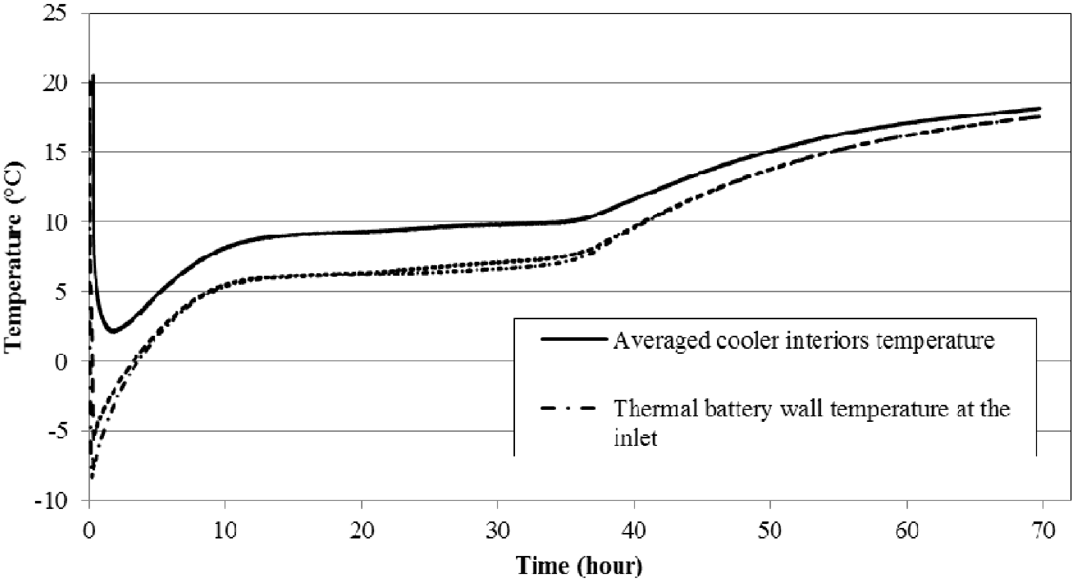

Figure 3. Temperature behaviors inside the passive cooler and on the thermal battery wall

CONCLUSION

The charging performance for a cooling unit, also introduced as a thermal battery was tested experimentally. The charging meant the freezing of the phase change material (PCM) within a series of aluminum channels and metal foam blocks impregnated with the PCM. It was proven that there was an improvement in terms of freezing time compared to common practice involving the chilling of the commercial cold packs already being used in pharmaceutical logistics. Short-term future work will involve the construction of the thermal battery with exactly the same dimensions but without the metal so that the influence of the thermal conductivity enhancement via metal foams can be further quantified. In order to increase the performance of the passive cooler, another thermal battery with again metal foam-PCM combination will be produced and tested as another short-term future work.

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