An experimental study of the temperature evolution of a single fin submerged in a phase changing material during melting at different heat fluxes

To cite this article: R Tassenoy et al 2021 J. Phys.: Conf. Ser. 2116 012047

View the article online for updates and enhancements.
An experimental study of the temperature evolution of a single fin submerged in a phase changing material during melting at different heat fluxes

R Tassenoy¹, W Beyne¹, W Plas¹, S Lecompte¹,² and M De Paepe¹,²

¹ Department of Electromechanical, Systems and Metal Engineering, Ghent University
Sint-Pietersnieuwstraat 41, B9000 Gent, Belgium
² FlandersMake@UGent – Core lab EEDT-MP, flandersmake.be

E-mail: Robin.Tassenoy@UGent.be

Abstract. An experimental setup has been designed to study a single cylindrical fin placed in a cylindrical enclosure filled with phase changing material (PCM). The heat flux to the fin is measured at the top of the fin. The temperature evolution at different fin heights is measured by thermocouples placed internally in the fin. The evolution of these temperatures has been studied for different heat fluxes. This provides insight in the contribution of the different fin heights to the total heat transfer to the PCM during the different stages of the melting process. As such they can be used to assess the effectiveness of the fin over its length. After approximately 6h, the fin temperature stabilizes during melting. Due to the temperature drop over the fin, the bottom temperature reached is significantly lower than the temperature at the top and the contribution of this lower part to the total heat transfer is lower as well. For heat fluxes higher than 3805±75 W/m², the steady-state temperatures at fin locations in contact with the melting PCM are similar. For low heat fluxes, this steady-state temperature is not reached during a 12h experiment. Longer experiments are thus needed to study the steady-state behaviour at these lower heat fluxes.

1. Introduction
Phase change materials (PCM) are used to store thermal energy in latent heat thermal energy storage systems (LTES). In LTES a phase change increases the amount of heat stored compared to traditional sensible heat systems, without a corresponding increase in temperature. In most systems, the solid-liquid phase change is used in LTES because of the high storage capacity and limited volume change during this phase transition [1]. The main drawback of most PCMs is their low thermal conductivity, which can inhibit a proper functioning of the LTES. Fins are often applied to enhance the conductivity of these materials because of their simplicity, ease of fabrication, low cost and additional heat transfer surface. Based on these criteria longitudinal, circular, plate and pin fins are most often used [2]. In this study focus has been given to pin fins. Pin fins are studied mostly in the context of heat sinks, where multiple fins are studied simultaneously. The optimal fin volume fraction, cross-section and PCM-fill rate have been studied [3, 4]. These parameters are found to influence each other and the need of an in-depth study of the fin length has been stressed [4]. To study the fin length, the problem is simplified to its most simple form: a single fin isolated in an enclosure. It is known the geometry of both the fin and the enclosure influences the heat transfer [4, 5]. Therefore, this study will focus on the behaviour of a single cylindrical fin placed in a cylindrical enclosure. The study aims to give a first insight in the fin effectiveness by discussing the temperature evolution of the fin over its length at different heat fluxes.
2. Methodology

2.1. Experimental apparatus

A schematic of the test section is shown in figure 1. The test section consists of four main sections: the enclosure filled with PCM, the heat transferring section, the additional support and sealing and finally the insulation.

![Figure 1. Schematic of the test section.](image)

The PCM is indicated in yellow in figure 1. RT35HC from Rubitherm Technologies GmbH (Berlin, Germany) is used [6]. The material properties of this PCM are listed in table 1. The PCM is placed in the actual enclosure (blue). This enclosure is made of polyacetal (POM-C). It has an inner diameter of 170mm and a height of 160mm. At the top of the container, two valves are provided. These can be used to fill the enclosure and can be opened to allow expansion of the PCM if needed. The heat transferring section adds heat to the enclosure and is indicated in orange/brown in figure 1. From top to bottom, it consists of a brass upper fin, the heat flux sensor and the stainless steel lower fin. Heat is added by circulating a hot ethylene glycol-mixture (52.87 mass %) through a tube brazed to the upper fin. Heat is conducted through the heat flux sensor to the lower fin. This lower fin is made from stainless steel (SS). The higher thermal conductivity of the brass upper fin (120W/(mK)) ensures a homogeneous heat flux through the heat flux sensor, while the lower thermal conductivity of the SS-fin (16W/(mK)) increases the measurability of the temperature difference in the axial direction. The outer diameter of both fins is 60mm. The brass fin is thickened at the top to make space for the tubes of the heating circuit. The SS-fin has an outer diameter of 80mm at the top, in order to keep it in place. It is inserted 125mm into the enclosure. The additional support and sealing (green) ensure good contact between both fins and the heat flux sensor and allow to exert a sufficiently high pressure on the gasket in between the RVS-fin and the top plate of the container for sealing, without crushing the sensor. Viton-rubber inserts are used as sealant. Finally, the enclosure is insulated (grey). Insulating tape is inserted in between the brass fin and the support plate to avoid conduction from the fin to the top plate. In between the support plate and the top plate of the container 10mm ceramic fiber insulation is added to avoid heat losses through the top of the container. The whole setup shown in figure 1 is surrounded with 18cm of glass wool placed in a polyurethane (PUR)-box.
Table 1. Material properties of RT35HC [6].

| Property                        | Value  | Unit     |
|---------------------------------|--------|----------|
| Melting temperature range       | 34-36  | °C       |
| Latent heat of fusion           | 210    | kJ/kg    |
| Specific heat capacity          | 2      | kJ/(K*kg)|
| Thermal conductivity (solid/liquid) | 0.2  | W/(m*K)  |
| Density (solid/liquid)          | 880/770| kg/m³    |

The temperature of the SS-fin is measured at 5 locations by K-type thermocouples. The experimental uncertainty analysis showed that the accuracy of all temperature measurements is within ±0.20°C. The position of these thermocouples is indicated in figure 1. The thermocouples are positioned internally in the fin to not disturb the heat transfer at the fin-PCM-interface. A hole has been provided in the middle of both fins to let the thermocouple cables pass. This hole has an internal diameter of 25mm. The heat flux sensor is positioned in between the brass and SS-fin. It is custom made by Captec Enterprise (Lille, France). The outer and inner diameter is respectively 60mm and 25mm. These diameters correspond with those of the fin. The sensor generates a voltage which depends on the heat flux through it. The sensor has a sensitivity of 9.2µV/(W/m²). According to the error analysis, the absolute accuracy of the heat flux measurements is within ±75,0 W/m² for all measurements. The thermocouples and the heat flux sensor are read out using a National Instruments cDAQ-9178 Compact DAQ-chassis. A NI-9213-module is used to read out the thermocouples. The voltage generated by the heat flux sensor is read by a NI-9205-module. The DAQ is connected to a PC LabVIEW 2018 is used to sample both measurements every 0.5s. The data is written to a .txt-file. Postprocessing of the measurements is done using Python 3.7.3.

2.2. Experimental matrix
The heat flux towards the enclosure cannot be controlled directly. Instead the temperature of the glycol-mixture is controlled and kept constant during a whole experiment. As such, the upper fin is heated and heat is conducted to the enclosure through the heat flux sensor. Five experiments have been carried out. The tested glycol-mixture temperatures are 60°C, 70°C, 80°C, 90°C and 100°C. Each experiment has a duration of 12h. During the experiments, the valves at the top of the enclosure have been closed. The enclosure contained 2.1 ± 0.1kg PCM. This leaves an airgap at the top of the enclosure to allow expansion of the PCM during melting and avoid failure of the container.

3. Results

3.1. Temperature evolution over the fin length
The applied heat flux at a heating fluid temperature (HFT) of 80°C is shown in figure 2. Initially, the heat flux rises quickly because the brass fin is heated by the hot glycol-mixture. This heat is conducted through the upper fin and the heat flux sensor to the SS-fin. Once the top of the SS-fin is heated, the temperature difference over the heat flux sensor drops and the heat flux itself drops too. After approximately 6h, the heat flux stabilizes at 3805±75 W/m². The corresponding temperatures over the fin length are shown in figure 3. The temperature at the top of the fin rises first. Due to conduction through the fin, heat is conducted to the lower part and finally the temperatures at the bottom of the fin start rising as well. The temperature drop over the fin is caused by the thermal resistance of the fin, convection to the PCM and heat transfer to the fin hole. After approximately 6h, the temperature increase of the fin becomes small. This means the heat added at the top of the fin is no longer used to heat up the fin, but an equilibrium is established between the heat input and the heat transfer to the PCM. Remark
that the temperature at the bottom of the fin stabilizes at 39.2°C, only slightly higher than the melting temperature. This means this part has hardly contributed to the melting of the PCM. Melting of the PCM is not completed in the studied timespan. If this would be the case, a temperature increase is to be expected once the melting is finished.

**Figure 2.** Heat flux for a HFT of 80°C.

**Figure 3.** Temperatures for a HFT of 80°C.

### 3.2. Influence of the heat flux

The temperature of the glycol-mixture has been varied, which alters the heat flux to the enclosure. Two fluxes higher and two fluxes lower than the base case have been tested (figure 4). The qualitative evolution of the temperatures over the fin length is similar in all cases. At lower heat fluxes, the temperature increase happens slower however. In general, the higher heat fluxes result in higher fin temperatures over the fin length. This effect is most pronounced at the top of the fin, where the fin does not make contact with the PCM. At the bottom of the fin, the temperature difference between the tested heat fluxes is significantly smaller. For the three highest fluxes tested (higher than 3805±75 W/m²), the steady temperature reached after approximately 6h is almost equal there. For the two lowest heat fluxes, the bottom temperatures are still lower after 12h, but the temperature is still rising. Steady-state has thus not been reached in 12h and longer experiments are needed to study these lower fluxes.

**Figure 4.** Heat flux for different HFTs.

**Figure 5.** Temperature T1 for different HFTs.

**Figure 6.** Temperature T4 for different HFTs.

**Figure 7.** Temperature T5 for different HFTs.
4. Conclusions

The fin temperature of a fin submerged in PCM has been studied at different locations during the melting process. Initially, the fin temperature rises but stabilizes at a fairly constant temperature after 6h. Due to the temperature drop over the fin, the bottom temperature reached is significantly lower and the contribution of this lower part to the total heat transfer is lower as well. For heat fluxes higher than $3805\pm 75$ W/m², the steady-state temperatures at fin locations in contact with the melting PCM are very similar. For low heat fluxes, this steady-state temperature is not reached during a 12h experiment. Longer experiments are needed to reach steady-state temperatures at all measurement locations.

References

[1] Chandel S and Agarwal T 2017 Review of current state of research on energy storage, toxicity, health hazards and commercialization of phase changing materials Renew. Sust. Energ. Rev. 67 581-96

[2] Abdulateef A, Mat S, Abdulateef J, Sopian K and Al-Abidi A 2018 Geometric and design parameters of fins employed for enhancing thermal energy storage systems: a review Renew. Sust. Energ. Rev. 82 1620-35

[3] Baby R and Balaji C 2012 Experimental investigations on phase change material based finned heat sinks for electronic equipment cooling Int. J. Heat Mass Transf. 55 1642-49

[4] Arshad A, Ali H, Ali M and Manzoor S 2017 Thermal performance of phase change material (PCM) based pin-finned heat sinks for electronics devices: Effect of pin thickness and PCM volume fraction Appl. Therm. Eng. 112 143-55

[5] Dhaidan N and Khodadadi J 2015 Melting and convection of phase change materials in different shape containers: A review Renew. Sust. Energ. Rev. 43 449-77

[6] Rubitherm Technologies GmbH 2018 RT35HC datasheet URL: https://www.rubitherm.eu/media/products/datasheets/Techdata_-RT35HC_EN_09102020.PDF
Accessed: 2021-10-23