Effect of PCM fill ratio and heat sink orientation on the thermal management of transient power spikes in electronics

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Abstract. The goal of this paper is to investigate the usefulness of Phase Change Material based heat sinks in power surge operations. Experiments have been carried out on a PCM based heat sink for different fill ratios (0, 33, 66, and 99%) of the PCM and different orientations (0, 90, 180°) of the heat sink under constant and power surge heat loads. The heat sink with a fill ratio of 0% is considered as the baseline case for comparison. The heat sink with a fill ratio of 66% at 0° orientation recorded lower temperatures among all the fill ratios and orientations under both constant and power surge heat loads. Partial filling (66% fill ratio) of the PCM in the cavity is more effective than complete filling (99% fill ratio) in handling both constant and power surge heat loads.

1. Introduction
Most of the electronic equipment draws high power either during the starting of operation or when they start working on full load conditions. These devices generate more heat during power surges than during the usual working conditions. The power surges do not prolong for longer time, however, their magnitude is several times higher than the nominal heat loads. Active cooling systems to accommodate these short duration-high amplitude power surges demand large space and high external power. Effective thermal capacitors help in making designs that are not oversized by absorbing the extra heat generated over nominal heat during power surges. As a result, the active assist cooling devices such as fans or blowers can be designed for the average heating rather than peak fluxes[1]. The Phase Change Material based heat sinks are work as a good thermal capacitors [2]. The supremacy of PCM incorporated heat sinks is due to their remarkable characteristics like high latent heat, high specific heat capacity. The major drawback of PCMs is, most of them possess low thermal conductivity (< 0.5 W/mK). Thermal Conductivity Enhancers (TCEs) in the form of fins, baffles, or metal foams are used to increase the effective thermal conductivity of the PCM [3].

A lot of literature is available on PCM based heat sinks and the effect of TCEs on their performance when they are subjected to a constant heat load [4, 5, 6]. However, not many researchers have explored the use of PCM to deal with power surges. The present study focuses on the effect of different fill ratios and orientations on the performance of the heat sink for both constant and power surge heat loads.

2. Experimental test apparatus and procedure
A heat sink is fabricated by end-milling a rectangular block of aluminum. Figure 1a shows the schematic representation of the heat sink. The outer and the cavity dimensions of the heat sink
are $60 \times 60 \times 25$ mm and $41.7 \times 41.7 \times 20$ mm, respectively. The heat sink has 25 vertical fins with a square cross-section of side 2.36 mm and a length of 20 mm are added to enhance the effective thermal conductivity of the PCM. The PCM used in this study is n-eicosane. The properties of both aluminum and n-eicosane are the same as used in Ref. [2]. A heater, made up of a Nichrome wire wound over the mica sheet, is placed at the bottom of the heat sink to mimic heat generation in a practical case. A cork is attached at the bottom of the heat sink to minimize heat loss from heater to the ambient. The open cavity of the heat sink is shutter by using an acrylic sheet having a thickness of 15 mm.

A total of six K-type thermocouples having an uncertainty of $\pm 0.2 \, ^\circ C$ are used in this study. Among the six thermocouples, four are placed between the heater and the heat sink to measure the junction temperature. The remaining two thermocouples are used to track the temperatures of the PCM and the ambient, respectively. The average of the four thermocouple readings is treated as the heater temperature to evaluate the heat sink performance. The experiments are performed for different fill ratios (33, 66, and 99%) of the PCM to study the effect of fill ratio on the performance of the heat sink. The cavity is filled by 1/3 rd, 2/3rd, and completely with PCM to attain the fill ratios of 33, 66, and 99%, respectively. The experimental setup consists of a rotation mechanism to orient the heat sink in different angles to study the effect of orientation on the performance of the heat sink (see figure 1b). The orientations considered in this study are 0, 90, and 180$\, ^\circ$. The angle of orientation is defined as the angle between the axis parallel to the fins and the vertical (see figure 1b). All the experiments are performed in controlled ambient conditions having a temperature of 23 $^\circ$C. The free surface of the PCM is parallel to the base of the heat sink at the start of the experiments for all fill ratios and orientations. This results in the movement of PCM inside the cavity for the fill ratios of 33 and 66% in 90 and 180$\, ^\circ$ orientations. All the experiments are performed two times to check repeatability, and the maximum difference in the temperature and time are observed to be 0.6 $^\circ$C and 145 s, respectively.

**Figure 1.** a) Schematic view of the heat sink configuration b) Image showing the experimental setup of the current study

### 3. Results and discussion

Two cases of heat inputs are considered in this study, namely case I and case II. In case I, a constant heat of 6 W for the 1500 s and in case II, a constant heat of 6 W for 600s followed by the power surge of magnitude 30W for the 180 s are supplied to the heat sink through the heater. The total amount of energy supplied in both cases is the same and is equal to 9000 J.
3.1. Case-I: Constant heat input of 6 W for 1500 s

Figure 2a shows the heater temperatures for different fill ratios and orientations at the end of the 1500 s for a constant heat input of 6 W. From an intuition, one would like to guess that as the fill ratio of PCM increases, the temperature excursion of the heater decreases. However, in this scenario, i.e., after supplying 9000 J (6 W for the 1500 s) of heat, the heat sink with the fill ratio of 66% at 90° orientation recorded lower temperature than a fill ratio of 99%. Figure 2b shows the temperature-time history of the heater for different fill ratios at 90° orientation. The heat sink with a fill ratio of 0% always has a higher temperature regardless of the orientation. The PCM in the heat sink for a fill ratio of 33% is melted completely at the end of the 1050 s and enters into a sensible heating phase. As a result, the temperature of the heater at the 1500 s for a fill ratio of 33% is moderately high. At the end of the 1500 s, the PCM is still in the melting phase for fill ratios of 66 and 99%. Despite high latent heat capacity for the fill ratio of 99%, the movement of liquid PCM in the cavity results in lower heater temperature for the fill ratio of 66% at 90° orientation.

![Figure 2. a) Heater temperatures for different fill ratios and orientations at the end of the 1500 s for a constant heat input of 6 W b) Temperature-time history of the heater for different fill ratios at 90° orientation for a constant heat input of 6 W](image)

3.2. Case-II: 30W power surge at 600s

A 30W power surge is applied for 180 s after the 600s of a constant 6 W heat input. Figure 3a shows the variation of heater temperature for different fill ratios and orientations at the end of the power surge (at time t=780 s). At the end of the power surge, the heat sink with the fill ratio of 66% at 90° orientation records a lower temperature than one with a fill ratio of 99%. The minimum temperatures recorded for the fill ratios of 66, 99% are 39.6, 40.7 °C for case I and 55.2, 56.4 °C for case II. This result reveals that the complete filling of the PCM in the cavity is deemed to be uneconomical in both cost and weight perspective.

Although the amount of energy supplied(9000 J) is the same in cases I and II, the temperature rise in case II is significantly high compared to the case I at the end of heating. Figure 3b shows the temperature-time history of the heater for the fill ratios of 0 and 66% at 90° orientation for cases I and II. The temperature difference between the fill ratios of 0, 66% are 12.5 °C for the case I and 15.2 °C for case II. PCM based heat sinks are thus very effective in regulating the rise in heater temperature not only for constant heat input but also for power surges.

4. Conclusions

Experimental investigations were carried out to study the heat transfer characteristics of an aluminum heat sink with vertical fins of 25 in number. This study focused on the effect of
Figure 3. a) Heater temperatures for different fill ratios and orientations at the end of the 780 s for case II b) Temperature-time history of the heater for the fill ratios of 0, 66% at 90° orientation when the heat sink is subjected to constant and power spike heat inputs.

different fill ratios and orientations when the heat sink is subjected to two different heat inputs: case I) constant heat input of 6 W for the 1500 s and case II) power surge of 30 W for the 180 s after the constant heat input of 6 W for the 600 s. The total amount of energy supplied in both the heat inputs was the same and equal to 9000 J. The following conclusions are drawn from the study.

i) Using a PCM based heat sink with a fill ratio of 66% at 90° orientation, a reduction of 12.5 and 15.2 °C in the heater temperature is achieved compared to 0% fill ratio at the same orientation for cases I and II, respectively. One can conclude from this result that the PCM based heat sinks are very effective in dealing with both constant and power surge heat loads.

ii) The minimum temperatures recorded for the fill ratios of 66 and 99% are 39.6 and 40.7 °C for case I and 55.2 and 56.4 °C for case II. This result reveals that the complete filling of the PCM in the cavity is deemed to be uneconomical from the viewpoint of both cost and weight.

iii) Although the amount of heat input is the same, the energy supplied through power surge results in higher heater temperature than the constant heat input. A heat sink designed for constant heat loads may not accommodate power surges. An optimum heat sink must take care of power surges to protect electronic components under harsh circumstances.

5. References

[1] Sahoo S K, Das M K and Rath P IEEE Transactions on Components, Packaging and Manufacturing Technology 8 416
[2] Akula R and Balaji C Journal of Thermal Science and Engineering Applications 13 031014
[3] Akula R, Gopinath A, Rangarajan S and Balaji C 2021 International Journal of Thermal Sciences 159 106525
[4] Qu Z, Li W, Wang J and Tao W International Communications in Heat and Mass Transfer 39 1546
[5] Arshad A, Ali H M, Khushnood S and Jabbal M International Journal of Heat and Mass Transfer 117 861
[6] Gharbi S, Harmand S and Jaballah S B Applied Thermal Engineering 87 454