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Thermal Management of Mobile Devices *via* PCM

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Abstract

This study investigates the effectiveness of Phase Change Material (PCM)-based thermal management in portable electronic devices, particularly focusing on n-eicosane as a heat storage medium. The research examines the ability of a Heat Storage Unit (HSU) containing PCM to regulate chip temperatures in mobile devices such as Personal Digital Assistants (PDAs) and wearable computers. Experimental tests assess the impact of heat dissipation rates and the orientation of the HSU on temperature distribution. Findings reveal that PCM effectively absorbs excess heat during transient operation, maintaining chip temperatures below the critical threshold of 50° C for extended periods. However, high power dissipation can still lead to overheating, highlighting the importance of optimized heat source placement and PCM volume. The results underscore the potential of PCM-based passive cooling solutions for enhancing thermal performance in compact electronic systems.

Major Findings: *This study confirms that PCM-based thermal management effectively regulates chip temperatures in mobile devices, keeping them below 50°C during transient operation. However, the placement of heat sources and the volume of PCM play crucial roles in temperature distribution, as improper configurations can lead to localized overheating. While PCM enhances thermal stability, high power dissipation can still cause temperature spikes, necessitating additional design optimizations for improved performance.*

Keywords: *Heat Dissipation, Heat Storage Unit, Mobile Devices, n-Eicosane, Phase Change Material (PCM), PDA (Personal Digital Assistant), Temperature Distribution, Thermal Management*

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1.0 Introduction

The relentless advancement in mobile electronic technology has led to increasingly powerful and feature-rich devices packed into ever-smaller form factors. This miniaturization, coupled with increased processing power and functionality, has resulted in a significant rise in heat generation within these devices. Effective thermal management is now paramount to ensure reliable operation, prevent performance degradation, and prolong the lifespan of mobile electronics like smart phones, tablets, and wearable computers. Excessive heat can lead to a multitude of issues, including reduced battery life, decreased processing speed, and even permanent damage to sensitive components. Traditional cooling methods, such as heat sinks and fans, are often impractical or ineffective in the constrained environments of mobile devices. Consequently, there is a growing need for innovative and efficient thermal management solutions. One promising approach involves the integration of Phase Change Materials (PCMs) into the thermal design of these devices. PCMs offer a unique mechanism for heat absorption and storage through their phase transition, typically from solid to liquid. This latent heat capacity allows PCMs to absorb significant amounts of thermal energy while maintaining a relatively constant temperature, making them attractive candidates for regulating temperature fluctuations in mobile electronics. This work explores the application of PCMs for thermal management in mobile devices, investigating their potential to mitigate heat buildup and enhance overall device performance. Modern smart phones experience significant thermal challenges due to high-power applications such as gaming, advanced cameras, and continuous internet usage, leading to power dissipation levels of 2-6 W. This study proposes a passive Phase Change Material (PCM) cooling strategy, leveraging isotropic heat conduction to maintain electronic component temperatures below 85° C, offering an efficient alternative to conventional cooling methods like natural convection and heat pipes, which often fail under high-power conditions[1]. The study numerically investigates the thermal performance of substrate boards made of FR4, silicon cladding, and copper cladding under natural and forced convection (3 m/s and 5 m/s) with non uniform heat flux on nine electronic components. Results show that copper cladding significantly reduces electronic component temperatures by 30-47 °C at 5 m/s, lowers the required airflow velocity by 2 m/s, and decreases IC chip temperature by 1.50-11.12°C compared to FR4 and silicon cladding[2]. The study presents an implicit transient numerical analysis of a novel mini channel-coupled passive thermal system for cooling non-identical IC chips using Phase Change Material (PCM). Comparative analysis reveals that N-Eicosane offers superior cooling, reducing system temperature from 53.234°C to 51.520°C, with an additional 0.5°C drop over paraffin wax and 1.35°C over ATP 78 PCM[3]. Experimental studies on minijet impingement in tubular heat exchangers demonstrate innovative heat transfer enhancement, while ANN-GA optimization enables predictive IC chip placement for efficient thermal cooling. Additionally, recent evaluations highlight nanofluid applications in heat exchangers, water-saving hygienic faucets for public spaces in developing countries, and the effectiveness of twisted tape inserts with circular holes in enhancing forced convection heat transfer[4-9]. A review of electronic cooling technologies explores challenges and advancements in harsh environments, while a study on *Calophyllum inophyllum* biodiesel with dimethyl carbonate focuses on optimizing engine performance and emissions. Research on solar collectors using recycled aluminum cans enhances drying efficiency, and numerical analysis investigates substrate board thermal conductivity for electronic cooling. Additionally, aerodynamic efficiency is optimized through CFD and wind tunnel experiments, and fuzzy logic techniques are applied to predict heat transfer enhancement with twisted tape inserts in heat exchangers[10-18]. Studies on wavy corrugated twisted tape inserts in double pipe heat exchangers demonstrate significant heat transfer enhancement, with performance analysis highlighting their effectiveness in forced convection. Research on electronic cooling explores thermal performance across different substrate materials and advanced solutions for harsh environments, including PCM integration for smart phone circuit cooling. Additionally, wind rose analysis assesses temperature variation in wind turbines using sensor implantation, while numerical and experimental investigations examine the influence of overlapping angles on the strength and deformation of arc-welded curved plates[19-27]. A comparative study of mono-composite and metal leaf springs evaluates experimental and numerical performance, while real-time surface finish measurement

of stepped holding shafts is automated for precision. CFD simulations analyze heat transfer in counter-flow helical double-pipe heat exchangers, and an algorithmic approach automates HVACR duct design. Nanofluid applications enhance heat transfer in double-pipe heat exchangers, while an integrated vehicle safety approach explores novel bumper designs with energy-absorbing mechanisms. Additionally, green adsorbents are investigated for heavy metal removal, focusing on zinc ion uptake by *Tinospora cordifolia* biocarbon[28-34]. An investigation into the effect of transformation-induced plasticity steel plate thickness on the ultimate tensile strength of Nd:YAG laser butt-welded joints reveals its impact on weld integrity, while an experimental study examines the mechanical behaviour of mild steel curved plates under varying thicknesses. Computational research explores thermal management of IC chips using phase change materials, and fuzzy logic modeling predicts heat transfer performance in double-pipe heat exchangers with wavy twisted tape inserts. Additionally, the influence of oxygen-containing additives in unleaded gasoline on exhaust emissions is analyzed for potential environmental benefits[35-39]. CFD-based studies analyze performance enhancement of heat exchangers in thermoelectric generators, while experimental research explores PCM and nano-PCM composites for improving solar still productivity. Reviews on hybrid thermal management of battery packs highlight enhanced cooling using PCM, and recent advancements in solar stills focus on nanoparticle integration for higher efficiency. Additionally, investigations on thermosyphon solar water heating systems examine PCM incorporation, emphasizing its role in boosting thermal storage and overall system performance[40-46].

2.0 Experimental Setup

Four heaters, simulating electronic components, are mounted on a Heat Sink (HSU) designed for a PDA Figure 1. The HSU consists of four heat-transfer blocks and a metal template with PCM-filled cavities. This parallel, symmetrical design distributes heat and prevents PCM leakage. Heat from the heaters is transferred to the PCM, which absorbs it as it melts. The setup is enclosed, and temperatures are tracked over time. The aluminum HSU, chosen for its high thermal conductivity and light weight, acts as a heat sink. Its thermal strength allows it to withstand the maximum test temperature (115°C).

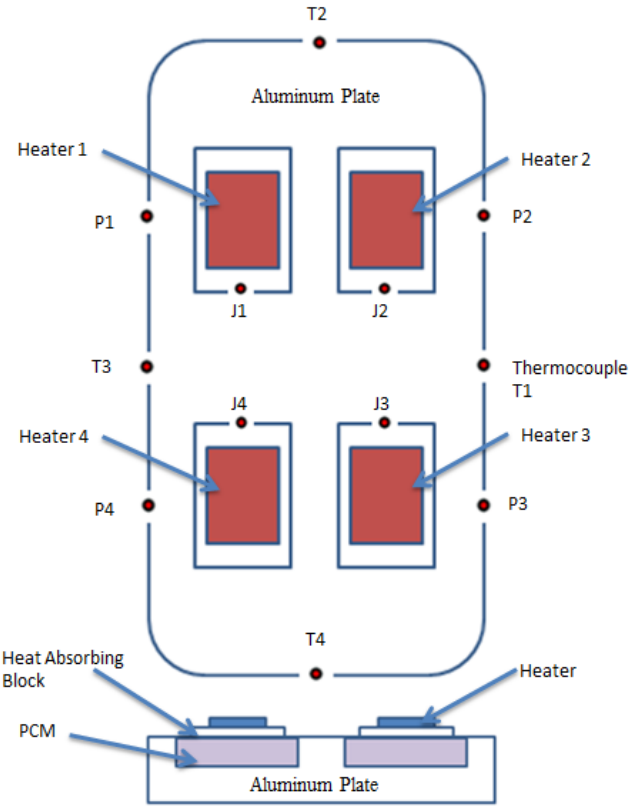


Figure 1. Heat source unit.

The uninsulated top promotes natural convection. Thermocouple holes are included, and screws secure the blocks to prevent leakage.

Aluminum heat-transfer blocks, each with a thermocouple hole, support 30W max heaters. K-type thermocouples, connected to a data acquisition system, monitor temperatures (T, P, and J - see Figure 1). A DC power supply powers the setup. Eleven two-hour experiments (Table 1) with a horizontal HSU and consistent 1W heat storage capacity were conducted. Molten n-eicosane was added, blocks and heaters (with thermal grease) were attached, and thermocouples were secured. Insulation was applied, heaters were connected (Table 1), and power was adjusted. Twelve HSU temperatures were recorded every 10 minutes for each experiment.

3.0 Results and Discussions

3.1 Case A

Case A simulated PDA cooling without PCM. Four 4W heaters distributed heat evenly, causing a rapid

Table 1. Experiments and the heater powers in cases A-D

Case	Type of Heating	Heater 1 (W)	Heater 2 (W)	Heater 3 (W)	Heater 4 (W)
A (Uniform heat)	Without PCM)	4.0	4.0	4.0	4.0
B (Uniform heat)	With PCM	1.0	1.0	1.0	1.0
		2.0	2.0	2.0	2.0
		4.0	4.0	4.0	4.0
C (Uniform diagonal heat)	with PCM	3.0	0.75	0.75	3.0
		4.0	1.0	1.0	4.0
		5.0	1.25	1.25	5.0
		4.0	1.0	1.0	4.0
		1.0	1.0	1.0	1.0
D (Non-uniform heat)	With PCM	0.73	0.73	0.73	6.6
		0.833	0.833	0.833	7.5
		1.0	1.0	1.0	9.5
		1.3	1.3	1.3	11.72

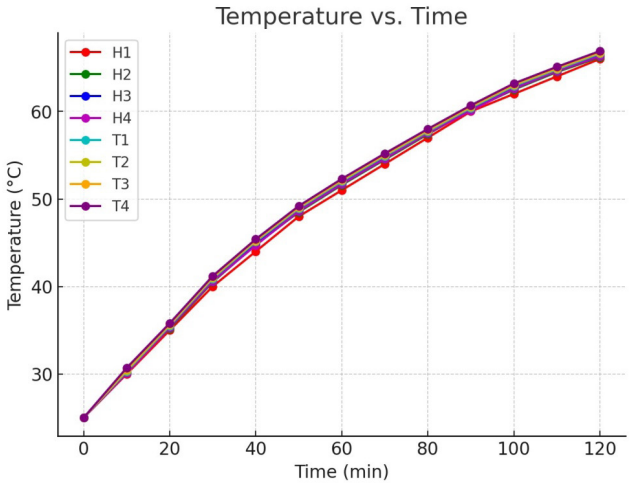


Figure 2. Case A temperature variation.

temperature increase (Figure 2), exceeding safe operating limits. This PCM-free setup serves as a baseline for comparison with later cases using PCM.

3.2 Case B

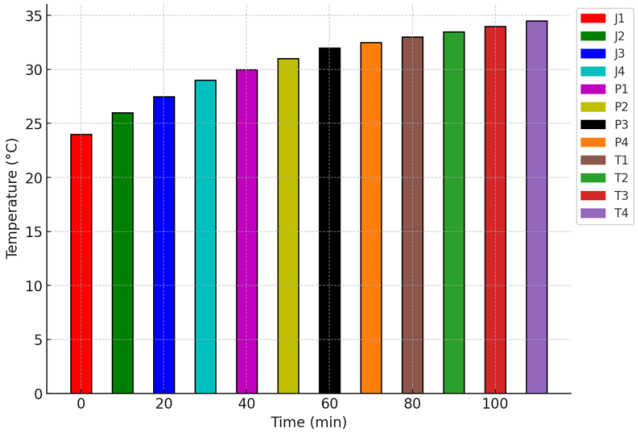
Case B used PCM-filled HSU cavities with even heat distribution (Figure 1, Table 1). 1W (Experiment 2), 2W (Experiment 3), and 4W (Experiment 4) heater powers were tested. Experiment 4's Phase 1 (PCM heating) took 10 minutes, Experiment 3 took 25 minutes, and Experiment 2 remained entirely in phase 1. Phase 2 (melting) started at 11 minutes (Experiment 4) and 26 minutes (Experiment 3), ending at 60 and 120 minutes, respectively, slowing temperature rise to 9° C (Experiment 4) and 3° C (Experiment 3). Phase 3 (melted PCM heating) only occurred in Experiment 4, showing a rapid temperature increase to 65° C (exceeding the 50° C limit). Junction temperatures stayed within limits for Experiment 2 and 3 but exceeded them in Experiment 4 after 75 minutes. Experiment 4 also had the shortest phase 1 and 2 durations (Table 2). Figure 4 shows PCM's benefit, delaying and stabilizing J1's temperature compared to the PCM-free case. The delay is PCM volume-dependent.

3.3 Case C

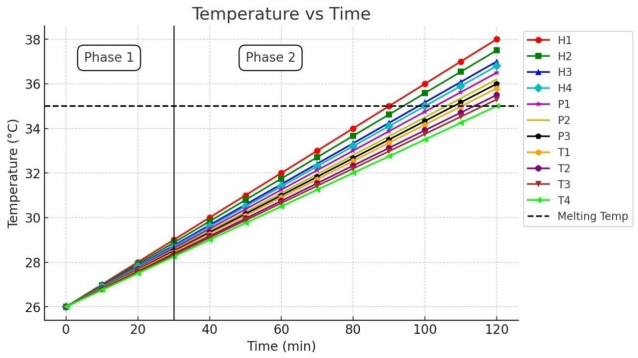
Case C used uneven heating (Table 1), with diagonal heaters at different powers. Temperature distributions were similar to Case B, so Figure 5 compares J1 temperatures. Phase 1 ended at 20 minutes (Experiments 5 and 6) and 10 minutes (Experiment 7). Phase 2 started at 21 minutes (Experiments 5 and 6) and 18 minutes (Experiment 7), ending at 120 and 85 minutes, respectively. PCM stabilized temperatures. J1-J4 showed highest temperatures. During Phase 2, junction-PCM temperature differences were <4° C (Experiment 5) and <9° C (Experiments 6 and 7). After Phase 2, Experiments 6 and 7 entered Phase 3, with rapid temperature increases. Only Experiments 5 and 6 stayed below 50° C (Table 2). Experiments 7 exceeded 50° C at 100 minutes.

3.4 Case D

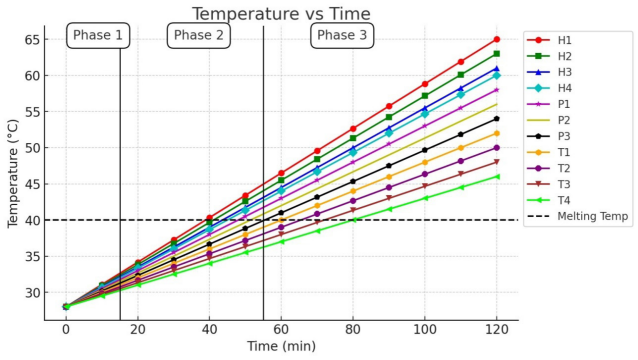
Case D used uneven heating, with one high-power heater and three lower-power heaters. Figure 6 shows J4 temperatures. Phase 1 took 20 minutes (Experiments 8-10) and 15 minutes (Experiment 11). During Phase 2, temperature rise slowed. Experiment 8 remained in phase 2. Experiments 9-11 exited Phase 2 at 110, 85, and 75 minutes, respectively. Phase 3 began after all PCM melted. Initial Phase 1 slopes were similar, with higher power leading to higher temperatures. Experiment 11 had the steepest increase. Experiments 8 and 9 remained in Phase 2. Experiments 8 and 9 stayed below 50° C, but Experiments 10 and 11 exceeded it (Table 2). Figure 7 compares Experiments 7 (Case C) and 10 (Case D), both at 12.5W. Despite similar power, temperature distributions differed. Experiments 7's J1 increased slightly faster in Phase 1, entering Phase 2 earlier. However, Experiment 10's J4 surpassed Experiment 7's after 30 minutes, with a 5° C lead, reaching 50° C 15 minutes later. A similar pattern was seen comparing Experiments 4 (Case B) and 11 (Case D). Heater placement affects temperature distribution, even with similar power.



(a) Experiment 2.



(b) Experiment 3.



(c) Experiment 4.

Figure 3. Experiments 2-4 in case B.

4.0 Conclusion

A series of experiments were conducted to investigate the temperature behaviour of a system designed to manage heat in a portable electronic device, likely a PDA. The setup involved four heaters positioned on top of a Heat Storage Unit (HSU) filled with n-eicosane Phase Change Material (PCM). The primary goal was to observe how the junction

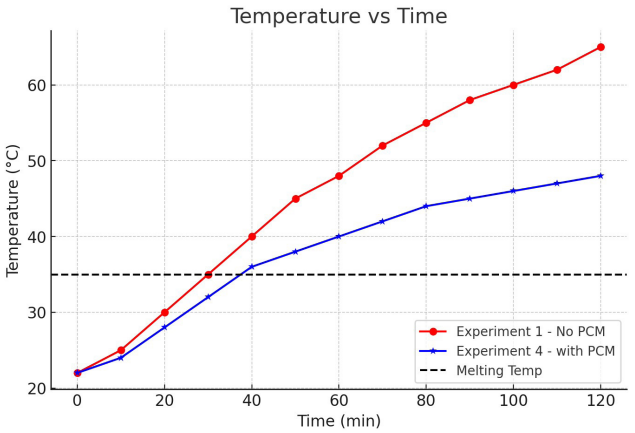


Figure 4. J1 temperature between Experiment 1 and Experiment 4.

Table 2. Highest temperatures in cases B-D

Case	B			C			D			
Experiment No.	2	3	4	5	6	7	8	9	10	11
Location of Thermocouples	J1-J4	J1-J4	J1-J4	J1-J4	J1-J4	J1-J4	J4	J4	J4	J4
Highest Temperature (°C)	38	42	68	40	50	58	44.5	49.6	61.2	72
<50 °C?	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	No
Time till Junction Temperature is 50 °C (min)	Nil	Nil	80	Nil	Nil	110	Nil	Nil	90	65

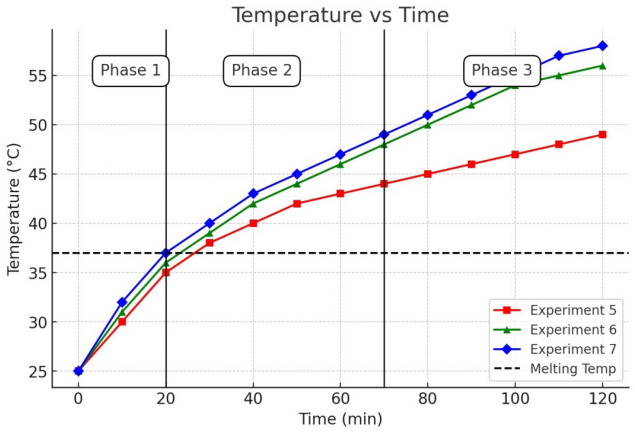


Figure 5. J1 temperature for experiments 5-7 (case C).

temperatures of the device's components, simulated by the heaters, would change over time, and to evaluate the HSU's ability to maintain these temperatures within an acceptable working limit of 50° C. The core function of the HSU, with its integrated PCM, is to stabilize the system's temperature. The PCM absorbs heat as it melts, effectively buffering temperature increases. However, the experiments revealed

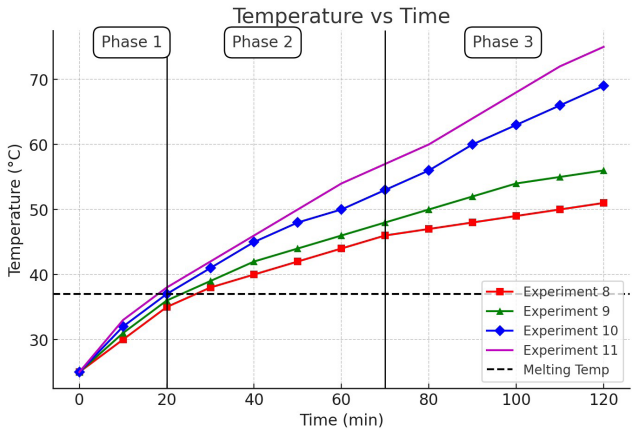


Figure 6. J4 temperature for experiments 8-11 (case D).

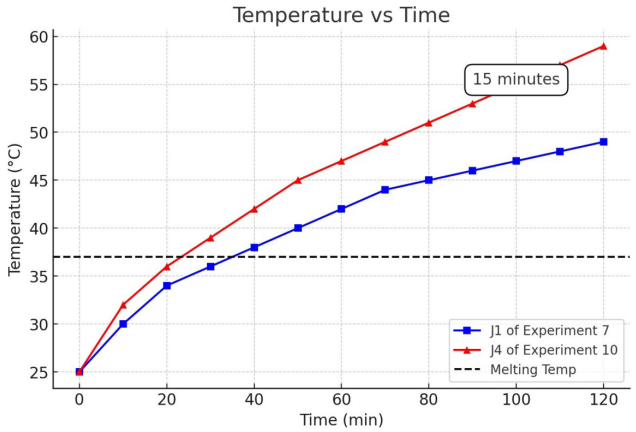


Figure 7. Experiment 7 (case C) and experiment 10 (case D).

a critical limitation: Under conditions of high power dissipation from the heaters, the junction temperature can still exceed the 50° C working threshold. This is a crucial finding, as it highlights the importance of carefully managing power consumption in these devices to avoid overheating. A key comparative scenario involved operating the system without the PCM in the HSU. As expected, the junction temperature in this case exhibited a rapid and uncontrolled increase. This underscores the vital role of the PCM in mitigating temperature spikes and maintaining a safe operating environment. The research also demonstrated that even with identical total power dissipation from the simulated components (the heaters), the distribution of heat across the HSU significantly influences the resulting temperature profile. Different heater configurations lead to varying heat flux distributions, which in turn affect how the PCM melts and how effectively it can absorb heat. Specifically, a configuration where a single heater dissipates a disproportionately large amount of power is more likely to generate localized hot spots and higher overall temperatures. This emphasizes the importance of optimizing the placement and power output of heat-generating components within the device. Finally, the study reinforces the direct relationship between the amount of PCM used in the HSU and its capacity to regulate temperature. A larger volume of PCM provides a greater thermal mass and more latent heat absorption capacity, extending the time the system can remain within the desired temperature range. This suggests that increasing the PCM volume, where possible, is a viable strategy for enhancing the thermal management capabilities of portable electronic devices, allowing them to operate safely for longer periods, especially under varying power loads.

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