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Passive thermal management of tablet PCs using phase change materials: Continuous operation

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ABSTRACT

Tablet computers (PCs) are continuously moving towards light, thin, and small shape factors to achieve an eye appealing design while providing extreme mobility. The increased integration of electronic components with high power density, smaller size, and more compact layout is leading to exceptionally high operating temperatures for tablet PCs. This research focuses on development of an inexpensive and practical solution for thermal management for tablet PCs using phase change materials (PCMs) encapsulated in thin aluminized laminated film. In this paper, the performance of the tablet PC with this PCM thermal energy storage (TES) unit under continuous operation was investigated. PT-37, a commercial PCM from PureTemp, and *n*-eicosane were used as PCMs, as they have been shown to be safe and relatively inexpensive, and have melting temperatures in the range suitable for thermal management of portable electronics such as tablet PCs. It was found that the insertion of the thin PCM-based TES system within that tablet PC resulted in a reduction of the rate of temperature increase, for both the electronics and the tablet cover, during the transient start-up phase of operation; leading ultimately, to lower operating temperature of the entire tablet. Findings from this research confirm that the implementation of PCM–based TES unit is a viable option for thermal management of tablet PCs.

1. Introduction

In recent years, tablet computers (PCs) have gained popularity over laptop computers due to their processing power being similar to an entry level laptop computer, yet with smaller form factors. The temperature management of laptop computer still rests for the most part on the use of a forced convection cooling solution, which is inexpensive and appropriate for the heat dissipation of such device. However, the high-power consumption of tablet PCs, coupled with their miniaturized shapes, makes using a forced convection fan-driven solution far from optimal for such devices (vibration and sound being two major issues fans create for such portable systems). The increase in heat generation of tablet PCs also has negative impacts on the long-term reliability of the device, as well as the thermal comfort of the user of the tablet PC holding it. Different studies [1–3] suggest that holding a tablet PC with a back surface temperature exceeding 42–45 °C can lead to a severe user discomfort. Besides, Joule heating of electronic components in tablet PCs (*i.e.* relays, resistors, transistors, etc.) causes their accelerated degradation, and hence reduces the life-span of the device [4]. For instance, the reliability of an electronic device can be reduced by 4% due to only 1 °C increase in the device's operating temperature limit [5], and an increase of 10–20 °C might double its failure rate [6]. Statistics show that more than 55% of electronic device failures are related to high-operating temperatures. All these facts have made tablet PC's manufacturers more concerned about their thermal management.

The achievement of a satisfactory thermal management solution of tablet PCs is closely related to the available space in the device. Indeed, unlike traditional active cooling in desktop computers which allows relatively large-scale heat sinks and fans, typical tablet PCs do not have sufficient space for the installation of a robust active thermal solution. Moreover, the divergence of Moore's law [7], offering twice the computational power at least every two years, and the slow improvement in battery technologies, with a battery power density that did not even double over the last decade [8], are forcing researchers to change their approaches for cooling tablet PCs away from reliance on battery power. Lately, phase change materials (PCMs) have attracted much attention as an alternative passive cooling technique for portable electronics [9–16]. Advantages of PCM-based systems include high latent heats of fusion, small volume change during phase change, low toxicity, low price, and absence of moving parts and external power source which provides

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Nomenclature

$C_{p,l}$	Heat capacity of liquid (J/g·K)
$C_{p,s}$	Heat capacity of solid (J/g·K)
g	Gravitational acceleration (m/s^2)
h	Convection co-efficient (W/m^{2}K)
k_s	Thermal conductivity of solid PCM (W/m·K)
k	Thermal conductivity of air (W/m·K)
L	Characteristic length of the tablet PC (m)
T_{onset}	Onset of melting Temperature (°C)
T_s	Surface temperature of the tablet PC (°C)
T_∞	Ambient temperature (°C)
$\Delta_{fus}H$	Latent heat of fusion (J/g)
β	Coefficient of thermal expansion (K^{-1})
ρ	Density of PCMs (kg/m^3)
υ	Kinematic viscosity (m^2/s)
θ	Inclination angle of the device (degrees)
Nu_L	Nusselt number
Pr	Prandtl number
Ra_L	Rayleigh number

unaltered standby time of tablet PCs. Properly selected, the PCM in such system absorbs and stores heat while the device is operating (charging phase of the PCM accompanied by melting). When the electronic device is idle, the melted PCM disperses heat to the surroundings and re-solidifies (discharging phase). The temperature rise of tablet PCs can be delayed until the PCM is fully melted, as the melting process occurs at a constant temperature. Obviously, this solution is applicable for devices that do not operate constantly since idle periods are required for the delayed heat to be rejected to the environment.

Alawadhi et al. [9] examined a physical model to mimic a portable wearable device, a system having a polymer (epoxy) body with a heater that simulated the electronic device's system on a chip (SoC). Their experimental results demonstrated that a TES unit (101 × 68 × 12 mm^3) was effective in controlling the source temperature. The system temperature was almost constant for constant power input situations using the PCM-TES unit. Their experimental work established the feasibility of the concept of cooling electronic devices using PCM-based TES units. Kandasamy et al. [11] investigated the phase change process of paraffin wax at different power levels and angular orientations of the PCM enclosure. They found PCMs to be very effective during transient operation of their 14-mm thick device. They suggested careful consideration of the thermal resistance between the PCMs and the environment which becomes important during heat rejection cycles. Hodes et al. [12] experimentally presented transient thermal management of a handset (holder cellular phone), a portable electronic device, using tricosane encapsulated in a 10-mm thick PCM container. Only 9.5 g of tricosane provided five times longer operation before reaching the critical set-point temperature (62 °C) for 3 W of power supplied. In a similar study, Tan, et al. [13] experimentally assessed the thermal performance of a PCM cooled mobile phone with different usage loads and orientations, using a PCM-based TES unit of 21 mm in thickness. They reduced by 6.4 °C the peak surface temperature of their device for both frequent usage condition and heavy usage condition. In an earlier study, they built an experimental setup using a PCM (*n*-eicosane) filled cavity (of unspecified thickness) embedded in a personal digital assistant (PDA) to investigate its cooling performance [14]. However, their PDA setup consisted of an aluminum block, heat transfer block and heaters, a setup that is not representative of an actual PDA. Another group, Kandasamy, et al. [15] instead used a FR4 sheet, plastic quad flat package (QFP) with copper lead for a standardized setup [17] to achieve a better representation of electronic devices. In their tests, the use of PCMs (placed in a 12.5 mm thick finned heatsink) resulted in a 10 °C lower skin temperature compared to the skin temperature of the system with an empty heatsink for 4 W heat input during unsteady operation. After 30 min of operation, the junction temperature did not reach their critical value (90 °C), whereas in the case of baseline operation (no PCM – no heatsink), it took only 6 min to reach the peak junction temperature.

The review of the aforementioned research illustrates that the use of PCM-based TES units for the thermal management of portable electronic devices is a viable option. Due to dramatic increase in the compactness of portable electronic devices (today's typical thickness on the order of 10 mm for the complete tablet PCs), PCM-based TES units as described above would be much too thick, limiting their use to larger systems, for example cooling of stationary electronic devices such as desktop computers or server level system on a chip (SoC).

Recent studies look at thin solutions suitable for today's tablet PCs and smartphones. Tomizawa et al. [16] investigated the thermal response of a mobile device equipped with a microencapsulated PCM (MPCM) sheet. Their experimental model had dimensions encountered in today's tablet PCs (thickness of 14 mm). The MPCM sheet was made by mixing 50 wt% polyethylene and 50 wt% PMCD-32SP paraffin (32 °C melting temperature). The MPCM sheet (thicknesses 1.60 mm–2.45 mm) was able to delay the saturation time of both heater and skin temperature. The delay was almost 5 min for the heater and 7 min for the skin. They additionally compared their MPCM sheet results with cases where only PCM is employed in thermal management system. Interestingly, their study showed that PCM alone performs even better. PCMs provided 16% and 24% additional delay for the heater and skin respectively before reaching the saturation temperature compared to the MPCM sheet. Numerical work looking at identifying the right melting temperature of the PCM placed in a thin layer between the device's SoC and the back cover showed that a range between 35 and 41 °C would be ideal [18]. The present authors also have been performing experimental work characterizing the thermal behavior and heat transfer characteristics of 2-mm thin PCM packages made of aluminized film of the sort used in this study [19].

Therefore, this paper presents the first part of an experimental study of temperature management, using a thin PCM package, of a tablet PC under continuous, constant power, operation. The novel PCM-based TES unit uses an aluminized laminate film (nylon/Al/polypropylene) as encapsulation; the average thickness is only 2 mm (1/16 in.) which makes it a good fit for today's thin tablet PCs. The experimental setup used is highly representative of today's tablet PCs, both physically and thermally, since it is built out of a Dell Venue tablet. Results from experimental tests performed with varying PCMs, TES unit size, power input level, and angular orientation of the device are presented herein.

2. Experimental setup

2.1. Phase change material

The main selection criterion of PCMs for this study was their melting temperature. Sponagle et al. [18] showed numerically that PCMs with melting temperatures of 43.3 and 55.8 °C did not completely melt under the conditions expected during the use of tablet PCs, and hence did not provide significant latent heat storage in the TES system. Better results were obtained for PCMs with melting temperature of 32 °C. Indeed, it was found that such PCMs can provide an efficient thermal management of the tablet PC by reaching a fully melted state after 30 min of operation. Based on that numerical study, two PCMs were selected: *n*-eicosane and PT-37 (a commercial PCM manufactured by PureTemp) with melting temperatures of 35.6 and 36.3 °C, respectively. Research on PT-37 and *n*-eicosane has shown that both PCMs have good chemical stability under 10,000 and 4000 melting-solidification cycles respectively [20], which comply with the required long-term system design