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ScienceDirect
International Communications in Heat and Mass Transfer 34 (2007) 801 – 808
International Communications in HEAT and MASS TRANSFER
www.elsevier.com/locate/ichmt

Effect of orientation for phase change material (PCM)-based heat sinks for transient thermal management of electric components ☆

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Available online 25 April 2007

Abstract

Phase change material (PCM)-based heat sink, consisting of a conventional, extruded aluminum sink embedded with appropriate PCMs, can potentially be used for cooling of mobile electronic devices such as personal digital assistants (PDAs) and notebooks which are operated intermittently. During the use of such mobile devices, the orientation changes from time to time. A numerical investigation was carried out to study the effect of orientation of heat sink on the thermal performance of the combined cooling system to determine if it affects the thermal performance of a PCM-based cooling system significantly.

Keywords: Heat sink; Phase change material; Electronic cooling; Orientation

1. Introduction

Thermal management is one of the most significant bottlenecks in the development of advanced microprocessors for mobile devices [1], such as personal digital assistants (PDAs), mobile phones, notebooks, digital cameras, etc. which are operated intermittently. Gong and Mujumdar [2–4] carried out a series of numerical studies on heat transfer during melting and freezing of single and multiple PCMs. Casano and Piva [5] investigated the periodic phase change process of a plane PCM slab numerically and experimentally. Jiji and Gaye [6] examined analytically one-dimensional solidification and melting of a slab with uniform volumetric energy generation.

The low thermal conductivity of PCMs presents a significant challenge in the design of PCM-based electronic cooling systems. In order to overcome this drawback, researchers have proposed various heat transfer enhancement techniques e.g. use of partitions/fins, graphite/metal matrices, dispersed high-conductivity particles in the PCM, and micro-encapsulation of PCM [7,8]. Use of PCM-based heat sinks is an effective way for cooling applications for electronic devices, as discussed by Pal and Joshi [9]. Tan and Tso [10] experimentally studied the cooling of mobile electronic devices using a heat storage unit filled with *n*-eicosane inside the unit. Krishnan et al. [11] proposed a hybrid heat sink which combined an active plate fin heat sink with the tip immersed in a passive PCM. Using scaling analysis of the governing two dimensional unsteady energy equations, Akhilesh et al. [12] presented a thermal design procedure to maximize the energy storage and operating time for a composite heat sink consisting of an elemental heat sink, PCM, and highly conductive base material. Recently,

☆ Communicated by A.R. Balakrishnan and S. Jayanti.

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0735-1933/$ - see front matter
doi:10.1016/j.icheatmasstransfer.2007.03.008

Nomenclature

A	porosity function
A,B	constant in Eq. (5)
C	constant
c_p	specific heat, J/kg K
g	gravitational vector, m/s^2
ΔH	latent heat, J/kg
H	height of heat sink, mm
h	heat transfer coefficient, W/m^2 K
h	specific enthalpy
h_{b}	height of heat sink base, mm
h_{f}	height of fin, mm
k	thermal conductivity, W/m K
L	length of heat sink, mm
l_b	PCM width, mm
l_t	fin width, mm
q''	heat flux, W/m^2
S	momentum source term
ΔT	temperature difference, K
T	temperature, K
t	time, s
u	velocity, m/s
x	coordinate, m

Greek symbols

α	volume fraction in multiphase media
β	thermal expansion coefficient, 1/K
χ	dimension scale
μ	dynamic viscosity, kg/m s
ϕ	liquid fraction
ρ	density, kg/m^3
ε	constant
0	initial value

Subscripts

i	component
L	liquid phase of PCM
m	melting
max	maximum
n	nth phase
w	bottom wall of heat sink

Kandasamy et al. [13,14] also investigated the feasibility of using PCMs for application in the thermal control of portable electronic devices. Wang et al. [15] numerically studied the two-phase model of PCM-based heat sink and examined the effects of some important parameters, such as PCM volume fraction, temperature difference, physical scale, and PCM properties, on the thermal performance of the combined cooling system.

Modeling of phase-change processes presents a significant challenge due to the complexity of the nonlinear governing equations. Some important factors, which are generally neglected in previous studies, need to be incorporated in the numerical analysis, e.g. volumetric expansion due to the phase change, convection in the liquid phase, and motion of the solid in the melt due to density differences. The orientation of the mobile device will necessarily change from time