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Research Paper

Experimental study of the cooling performance of phase change material with discrete heat sources – Continuous and intermittent regimes

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HIGHLIGHTS

- Study on thermal performance of PCM with three discrete heat sources.
- Examination of heat transfer mechanism for different heat flux repartition between sources.
- An intermittent regime is investigated for different heat flux cycle.
- An extended critical time is shown when the greater part of heat flux is placed at middle or lower source.
- Fractionating cycle length into 4 or 8 cycles can keep plate temperature under critical condition for longer time.

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ABSTRACT

This paper presents an experimental investigation of phase change material (PCM, Plastic paraffin) behavior in a rectangular enclosure with three discrete heat sources flush-mounted on the right vertical wall. The remaining walls of the cavity are adiabatic. Maximizing the critical time (time required by one of the electronic components before reaching the critical temperature) is the global objective of this study. Conserving constant the total flux, the thermal performance of system is examined by different heat flux repartition between sources. Also, the intermittent regime is studied for different heat flux cycle. The results show that the thermal performance depends strongly on the heat flux repartition and the maximum heat transfer is seen for the lower source. Placing the greater part of heat flux at middle or lower source seems the best manner to extend the critical time. For intermittent regime, it is concluded that fractionating cycle length into 4 or 8 cycles can keep plate temperature under critical condition for respectively 3 and 5 times comparing to one cycle.

1. Introduction

With the progress of electronic devices development, they become more and more potential site of high power. Therefore, thermal control become an extremely challenge for electronic equipment safety and reliability. The major objective of interest for the cooling is maintaining the component temperature below a maximum limit.

In recent years, using PCMs for electronic cooling presents a promising technique. By absorbing the heat generated by components it offer a relatively large period of temperature stabilization. Kandasamy et al. [1] studied numerically and experimentally the use of PCM (Paraffin wax) based heat sink for thermal management of portable electronic devices under cyclic steady conditions. It was concluded that using PCM-based heat sinks improve the thermal performance of electronic component during intermittent use. For cooling portable hand held electronic devices, Tan and Tso [2] investigated experimentally a heat storage unit filled by PCM (n-eicosane). They reported that the use of PCM can stabilize the temperature system and extend the operation time. Faraji and El Qarnia [3] analyzed numerically cooling of microprocessors using a PCM heat sink in a cyclic operating mode. It was found that the established periodic mode was reached after three cycles of working. Gharbi et al. [4] conducted an experimental analysis of different configurations of heat sink based PCM (Plastic paraffin). The results indicated that the inclusion of PCM can lower component increase temperature and the combination of PCM and long, well-spaced fins presents an effective means for thermal control of electronic devices.

In most applications, multiple components dissipate heat mutually and periodically during the operating period. Therefore,

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Nomenclature

C_p	specific heat capacity, kJ kg^{-1} K^{-1}
F	amplitude
g	gravitational constant, m s^{-1}
H_l	liquid fraction
H	heat source
k	thermal conductivity, W m^{-1} K^{-1}
L_m	melting heat, kJ kg^{-1}
PCM	phase change material
P	pressure, N m^{-2}
Q	heat flux, W m^{-2}
T	temperature, °C
t	time, s
U, V	velocities, m s^{-1}
ρ	density, kg m^{-3}
μ	dynamic viscosity, Pa s
β	volumetric expansion coefficient, (1/K)
amb	ambient
c	critical
eq	equivalent
0	reference
1, 2, 3	upper, middle and lower heat source
gr	great part of heat flux
l	liquid
m	melting
w	weak part of heat flux
s	solid

cooling discrete sources have received a great interest by many authors. Keyhani et al. [5] performed an experimental study on natural convection heat transfer in a tall vertical rectangular enclosure with an array of eleven discrete heaters. It was showed that compared to the uniformly heated vertical wall, the discrete heating in the cavity augments more the local heat transfer rate. Chadwick et al. [6] have experimentally and theoretically investigated the heat transfer in a rectangular enclosure for single and multiple heaters attached on one vertical wall. It was revealed that for single and dual heaters, the higher heat transfer corresponds to the bottom heater location in the high Grashof number range. The optimum spacing problem was investigated by Liu and Phan-Thien [7]. For three heated chips mounted on a conductive substrate in a two-dimensional rectangular enclosure filled with air, the optimum thermal performance was found when the center-to-center distances between the chips follows a geometric series (the geometric ratio is the golden mean 1.618). More recently, in order to maximize the global conductance in enclosure, Kadiyala and Chattopadhyay [8] performed an optimization of location of heat sources in a vertical square enclosure with natural convection. The results showed that the optimal location of the three heat sources should be as close as possible to the bottom adiabatic wall.

Numerous studies have been performed on heat transfer in cavity discretely heated from below: Deng et al. [9] investigated numerically the interaction between two discrete flush-mounted heat sources at the bottom of an enclosure with insulating side walls. They examined the effects of the Rayleigh number, the thermal strength, and the separation distance on the interaction between sources. The result showed that the lowest maximum temperature is noted when the distance between sources is nearly close to height. Basak et al. [10] studied numerically laminar natural convection flow in a square cavity with uniformly and non-uniformly heated single bottom wall and adiabatic top wall. It was concluded that the sinusoidal nonuniform heating improves the heat transfer rates at the center of the bottom wall than the uniform heating case for all Rayleigh numbers.

Thanks to its high removal heat and energy storage density, using PCM may be a promising alternative for cooling multiple operating components. Research by Binet [11] developed a mathematical model (2D) of the thermal behavior of PCM (octadecane) inside a vertical rectangular cavity with three discrete heat sources. It was reported that cavities with a high aspect ratio (>4) show better thermal control of the heat sources and provide relatively long melting times. Yuwen et al. [12] conducted an experimental study on the melting process of the n-octadecane in a rectangular cavity with three protruding discrete heat sources. The effects of Stefan number, the sub-cooling and aspect ratio on the melting process were analyzed. It was concluded that the upper source has the higher temperature and subcooling weakens natural convection. Zhang et al. [13] studied analytically the melting of the PCM (n-octadecane) within a rectangular cavity heated by three sources flush-mounted on one of its vertical walls with adiabatic other walls. They evaluated the effect of heat source dimension and the conductivity of unheated part on thermal performance. The results obtained show that increasing heat source dimension reduces the surface source temperature. Also, with the increase of unheated part conductivity the upper source temperature rises while that of lower source decreases.

Faraji et al. [14] developed a 2D mathematical model in order to explore the behavior and the thermal performance of a vertical rectangular enclosure filled with PCM (n-eicosane) heated by three heat sources attached to a vertical wall. They concluded that the maximum temperature is at the central source when conduction is dominant, while the upper heat source stores this maximum temperature when the convection develops. The highest rate of heat transfer is observed for the lower heat source. El Qarnia et al. [15] performed a numerical study on the melting of PCM (n-eicosane) in a rectangular cavity heated by three heat sources mounted on a vertical conductive plate. They examined the effect of different parameters such as Rayleigh number and the inter-unit spacing on the thermal performance. The results indicate that the critical time is reduced by increasing the spacing between sources and the lower position of the sources shows the best cooling. Mirzaei et al. [16] studied numerically the melting of PCM (Paraffin 18 °C) in a two-dimensional horizontal annulus heated by two discrete heat sources attached at the inner cylinder keeping the rest of walls insulated. They examined the effect of heat sources arrangement on melting process. It was indicated that heat sources location on the bottom part show higher rate of melting.

From the previous literature, it was shown that most of studies on PCM with discrete heat sources have been restricted to geometric parameters evaluation such as heat source arrangement, size, length, spacing and enclosure aspect ratio. To the best knowledge of the authors, the manner of arranging different power component and intermittent regime are not yet been reported. Therefore, the focus of this paper is to investigate experimentally the melting process of a PCM in a rectangular enclosure with three discrete heat sources. In order to get closer to real applications and optimize the source emplacement, the effect of heat flux repartition between sources and intermittent periodic heat flux is evaluated on cooling performance of system based primarily on maximizing the critical time.