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Experimental passive electronics cooling: Parametric investigation of pin-fin geometries and efficient phase change materials

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ABSTRACT

This experimental investigation focuses on the optimization of passive cooling system using extruded finned surfaces with phase change materials (PCMs) as the thermal conductivity enhancers (TCEs). The study develops comparison between fins of circular and square cross-sectional area, made of aluminium. Further classification is done in configuration in terms of staggered and inline arrays. The volume fraction of fins is kept constant at 9% of total volume of heat sink. The purpose is to single out the better arrangement with and without PCM. Six PCMs of varying phase change temperature and heat capacities, namely Paraffin wax, RT-54, RT-44, RT-35HC, SP-31 and *n-eicosane* are selected for thermal conductivity enhancement. The volume fraction of PCM is also constant at 90% of the heat sink volume, giving a 10% volume for expansion after melting. Moreover, power levels are used in a range of 4–8 W with an increment of 1 W. The analysis was carried out on graphical trends produced and explanations were given accordingly. The most effective PCMs were also discussed considering their enhancement time, enhancement ratios and other material properties. Finally, the results were justified by the scientific knowledge and found in compliance with the work of famous researchers as well.

1. Introduction

Thermal control of modern electronics circuitry has become increasingly complex and it is very essential to ensure its reliability, durability and user comfort. Researchers are always in search of finding new effective solutions for thermal management of electronic devices. The choice of cooling techniques depends on number of factors. Active cooling and all other techniques have proven to be incapable of fulfilling the demands of modern electronic industries as it consumes power itself. So, passive cooling techniques employing PCM based heat sinks are used widely in these portable devices like computers, mobile phones, personal digital assistants, laptops and so on. Effective thermal management by incorporating PCM based heat sinks in these devices have led to increase in its functionalities, reliability, less probability to internal damages and failure, ultimately to stretch their useful life. Many studies both experimentally and numerically have been conducted to offer a deep insight into thermal management of electronic devices using PCM based heat storages.

Husseinizadeh et al. [1] examined both experimentally and numerically PCM based heat sinks to study the effect of various configurations of internal fins. The PCM RT-80 was filled in different heat sinks of constant overall dimensions. From the results obtained it was seen that by increasing number of fins, fin height and input power level had improved the thermal performance appreciably while increasing fins thickness had only marginal improvement. Similarly, Pakrouh et al. [2] presented numerical method for geometric optimization of pin finned heat sinks by coupling Taguchi and simulation method. For optimization, the effect of all critical parameters involving fins' number, thickness, base thickness, height as well as PCM percentage were explored. All heat sinks filled with RT-44 and critical temperatures 50 °C, 60 °C, 70 °C and 80 °C were selected for analysing the results. The 2 mm thick fins performance was highest for 50 °C while 4 mm thick fins performance was highest for all temperatures. Base thickness contributed less than the other parameters. Mahmoud et al. [3] investigated experimentally the effect of honeycomb structure in heat sink to compare its performance with finned heat sink. Six different types of PCMs and total six heat sinks, one with single cavity, two designed with parallel fins, two with cross arrangement and one with honey comb inserts were tested at

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Nomenclature

Roman symbols

Symbol	Quantity (Unit)
PCMs	Phase change materials
SPTs	Set point temperatures (°C)
T_{PCM}	Melting temperature of PCMs (°C)
T_{Al}	Melting temperature of aluminium (°C)
t	Thickness of fin (mm)
h	Height of fin (mm)
υ_f	Volume of the fin (mm^3)
V_f	Total volume of fins
N_f	Total number of fins
V_S	Total working volume of heat sink (mm^3)
m	Mass of the PCM (kg)
q	Heat flux (kW/m^2)
t_λ	Latent heat phase duration (sec)
T	Thermocouple inside the PCM
W	Thermocouple at side wall of heat sink
H	Thermocouple at base of heat sink
t_{cr}	Time to reach critical temperature (sec)

Greek symbols

ψ_{PCM}	Volumetric fraction of PCM
ν_{PCM}	Volume of PCM (m^3/kg)
ρ_{PCM}	Density of PCM (kg/m^3)
ρ_{Al}	Density of aluminium (kg/m^3)
ε_{PCM}	Enhancement ratio at PCM
λ_{PCM}	Latent heat of PCM (kJ/kg)
C_{PCM}	Heat capacity of PCM (kJ/kg)
C_{Al}	Heat capacity of aluminium (J/kg)
k_{PCM}	Thermal conductivity of PCM (W/m K)
k_{Al}	Thermal conductivity of aluminium (W/m K)
ϵ_A	Surface area ratio

power level in the range from 3 to 5 W. The obtained results showed that increasing number of fins, insertion of honey comb and inclusion of low melting temperature PCM at higher power level had enhanced significantly the operation time of heat sink. Fins had significant role in improving thermal performance of heat storage unit. Recent findings considered identifying optimum distribution of these TCE (fins) in terms of dimensions and shape. Saha et al. [4] carried out their research to investigate the effective way of distributing fins in heat sinks i.e. to find the optimum volume fraction of TCE which maintains a low temperature of any component. Using *n-eicosane* as PCM in aluminium made heat sinks. Two types of fins *(plate-fin* and *pin-fin*) were analysed in heat sinks with base dimension of 42×42 mm^2 and fins height of 25 mm. The case of 8% TCE volume fraction of heat sink or base plate was reported to give best results. Regarding fin dimensions and shape it was concluded that the large number of small cross-sectional area pin fins performed better.

Baby and Balaji [5] experimentally investigated three different geometries of heat sinks employing different no of TCE. All heat sinks were made of aluminium employing 33, 72,120 number of *pin-fins* of corresponding volume fractions were 4%, 9%, and 15% respectively. The effectivity of volume fractions of TCE was examined at power level 4–8 w using *n-eicosane* with varying volume fractions of 0.3, 0.6 and 1. For SPT of 43 °C and 8 W power, the highest enhancement factor of 21 was obtained for heat sink with 72 number of fins. Also, the performance was seen to be strongly dependent on PCM volume fractions instead of TCE volume fractions. The effect of orientation on thermal performance of porous matrix filled heat sink was investigated by Srikanth et al. [6]. Tracking system was employed to change the orientation of copper metal foam matrix embedded Al-heat sink filled with *n-eicosane*. The experimental results obtained in terms of enhancement ratios showed that the heat transfer enhancement was only comparable and effect of orientation has no significant impact on the mentioned heat sink.

Experimental work performed by Fan et al. [7] determined the effect of internal fins and melting temperatures on performance of PCM based heat sinks under pulsating heat loads. Two organic PCMs (*n-eicosane* and 1-hexadecanol) having different melting temperature were tested in prototype heat sinks at different power levels and it was concluded that the PCM with higher melting temperature had resulted in improved thermal performance of electronic devises comparatively. Six heat sinks designs were tested by Mahrous [8] to investigate the effect of fins arrangement and fin number, on thermal performance. Identical plate finned heat sinks with four heat sinks of parallel fins arrangement, one with crossed fins and one with no fins were tested. A constant fin thickness of 1 mm and constant power level 4.84 W was used and it was concluded that the parallel and crossed fins arrangement both had nearly comparable performance but performance of all fins heat sinks was superior to that without fins. Numerical study carried out by Levin et al. [9] explored the effect of fin's length, height and number for the optimal PCM percentage to be considered in designing latent heat thermal management system (LHTMS) for electronic devices. From the results, it was concluded that the optimal percentage of PCM is dependent on number and height of fins, heat flux and the difference between liquidus and critical temperature.

Thomas et al. [10] carried out numerical study for the design of PCM based heat sink for average dimensions of a smart phone. Analysis were performed using ANSYS FLUENT 14.0 by providing constant heat flux to the base of heat sink with power input ranging from 4 to 6 w. Eicosane was selected as PCM for designed heat sink. High performance was obtained when PCM fraction had reached to its maximum. Selection of thermal performance enhancement method has a vital role in thermal management of components. Nagose et al. [11] used combined genetic and conventional simulation to get optimized configuration of heat sink which kept the temperature of microprocessor in acceptable limits. The designed heat sink consisted of fin array with depth equal to heat sink and a heat spreader inside the heat sink. From the results obtained with the assumption of constant heat flux from electronic device correlations were proposed relating heat sink operational time to the PCM fraction, heat sink depth and heat spreader thickness. It was found that the optimal spreader thickness was 2.5% of heat sink depth.

Hatakeyama et al. [12] conducted their experimental and analytical research on PCM based transient cooling module employing pin fins. The setup used by them consisted of test module, heat spreader, chamber, substrate, power source, Data logger, three heat sinks with round fins of different number and diameter. The paraffin volume fraction used, was 81% of total space. Thermal network model of module was developed capable of predicting temperature transients. This model was reported to be effective design tool for thermal management of electronic devices. The research by Hassan et al. [13] investigated and compared the performance of three different types of PCMs namely salt hydrate, paraffin wax and milk fat in PCM based finned heat sink system. Experiments were conducted on finned heat sink at power input ranging from 4 W to 10 W. The conjugate heat transfer model was developed for each